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# THE USE OF COVER CROPS FOR THE MAINTENANCE OF RIGHTS-OF-WAY VEGETATION: A SURVEY OF THE LITERATURE ON SUCCESSION, COVER CROPS, COMPETITION AND TREES

Report No 89-275-K

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## ABSTRACT

A literature survey was undertaken to determine the current state of knowledge on the use of cover crops for the control of tree establishment and growth. There are few published accounts of cover crop usage by electrical utilities. The forestry and orchard industries have undertaken some research in cover crops. Some of this is promising, however none of the research was from an area comparable to Ontario. Additional research is required to identify potentially useful cover species and determine the feasibility of such an approach for rights-of-way vegetation control.



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## EXECUTIVE SUMMARY

# THE USE OF COVER CROPS FOR THE MAINTENANCE OF RIGHTS-OF-WAY VEGETATION: A SURVEY OF THE LITERATURE ON SUCCESSION, COVER CROPS, COMPETITION AND TREES

D. Brown

In recent years, Ontario Hydro has attempted to integrate a biological control strategy within the rights-of-way maintenance program. The intent of this strategy is to utilize properties inherent within the vegetation to slow down or stop the natural successional development towards a forest. There is evidence in the literature that the direction and rate of succession can be altered through the manipulation of the plant communities (either by adding or removing species, or altering the supply of resources).

The implementation of a biological control strategy has been undertaken by Ontario Hydro. Tree removal is accomplished using chemical and mechanical techniques applied in a manner that causes minimal disruption to the nontarget vegetation. The nontarget vegetation should then interfere with the invasion and growth of new trees through competitive, allelopathic and other interactions. The expected outcome is a reduction in tree density, an extension of the maintenance cycle, and a reduction in the amount of herbicide required to maintain the rights-of-way.

The success of this approach is dependent upon two factors: the presence of species in the existing community which are able to interfere with tree growth, and that these species will spread on the right-of-way. This can be considered as a passive approach to the application of a biological control strategy, and the successful establishment of a vegetation capable of exerting a high degree of biological control has been very elusive using this passive approach. The alternative is the active approach called cover cropping, where the right-of-way is planted with a cover crop species or group of species which have a previously demonstrated ability to interfere with tree growth.

Although cover crops have been used extensively for revegetation, erosion control and land reclamation projects, there is little published information available specifically related to vegetation control. Some studies in the south-east United States report a reduction in either tree density or maintenance costs for cover cropped rights-of-way (Arner 1960, 1966; Allsbrooks *et al.* 1984). On the west coast, researchers estimate that cover cropping will not allow adequate



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control, although promising results have been achieved through fertilization of the natural vegetation with either sewage sludge or urea (West 1987, Whitney *et al.* 1987). Unfortunately, due to difference in climate and vegetation, none of these studies are directly applicable to this province.

There are several published studies on the potential application of cover crops in the orchard and forestry industries, with the objective of increasing tree or fruit yield. Although this is the opposite effect to what is required in the utility industry, these studies have investigated the interference potential of approximately 70 different species and have identified species which inhibit tree growth more than the natural vegetation. Unfortunately, this is an insufficient data set to make recommendations, as only 14 of these species were tested in more than two studies. In addition, these experiments were conducted in areas not comparable to Ontario, therefore they are not directly related to our situation.

More research is required to identify species which are potentially useful for cover cropping in Ontario. Until these species have been identified, no valid comparison between a cover cropped right-of-way and the current herbicide or mechanical cutting methods can be made regarding the degree of control achieved by this approach.

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# THE USE OF COVER CROPS FOR THE MAINTENANCE OF RIGHTS-OF-WAY VEGETATION: A SURVEY OF THE LITERATURE ON SUCCESSION, COVER CROPS, COMPETITION AND TREES

## 1.0 INTRODUCTION

The major responsibility of an electrical utility is the delivery of an uninterrupted supply of power to its customers. This is achieved through a network of transmission and distribution corridors. The vegetation on these rights-of-way must be maintained in a low growing state to allow for ease of line maintenance, to ensure the safety of workers and the public and to eliminate tree-induced outages. The utilities have a responsibility to manage these rights-of-way in a manner that is both economically feasible and environmentally acceptable to the land owner and general public.

The options available for vegetation control can be broadly classified as chemical, manual, mechanical and biological. These are not mutually exclusive treatments. An efficient control program will utilize all four treatments to achieve the most desirable outcome. The chemical and mechanical treatment options have been extensively studied, and some information is available on the degree of biological control exerted by the plant communities produced under these various treatment regimes (Niering and Goodwin 1974; Bramble and Byrnes 1976, 1983; Allsbrooks *et al.* 1984; Dreyer and Niering 1986).

A biological control strategy can be broadly described as any combination of management techniques which attempts to maximize the vegetation's ability to resist tree invasion. This strategy has been applied to rights-of-way maintenance as a selection of chemical, manual and mechanical treatments which result in minimal disturbance to the ground vegetation. This is a passive approach to increasing the degree of biological control. An alternative would be an active approach involving the complete replacement of the natural vegetation by planting species which have exhibited a high degree of biological control. This active approach is often called cover cropping.

### 1.1 Succession

The use of a biological control strategy for vegetation management, either through the use of cover crops or selective maintenance of natural communities, is an attempt to control succession.

Thus an understanding of the theories and processes behind succession is important in the development of strategies related to conservation, exploitation or control of biological systems (Finegan 1984).

Succession is the directional change in species composition (plant, animal and microbial) at one location with time. The important aspect of this definition is that the change is directional, and not merely the random variation inherent in all biological systems or the cyclic changes observed in some communities.

The majority of successional studies have concentrated on forest communities, either as a recovery from a disturbance (fire, logging) or the invasion of abandoned agricultural fields. A generalized successionary pattern is a progression from a species mixture initially dominated by annual weeds, to one dominated by small perennials, followed by tall perennials, then shrubs and ultimately trees. Several theories have been proposed which attempt to explain all or part of this progression.

The classical interpretation of succession was presented by Clements (1916). Succession starts with a disturbance which causes unvegetated ground to become available. Only a few "pioneer" species with special characteristics are able to invade and establish in this area. The presence of these species causes a modification of the environmental conditions at the site. This change is favourable for the establishment of other species, but is less favourable for the growth of the pioneer species. (This was called the process of reaction by Clements.) Thus the species composition of the site changes from one dominated by pioneers to one dominated by second stage species. The second stage species again alter the environment, making the site more favourable for third stage species, and less suitable for the second stage species. This replacement series continues until a community is reached which can successfully invade itself. This is called the climax community.

The critical part of Clements theory is the process of reaction. The driving force behind succession is the vegetation itself, thus succession in a given area should always follow the same pattern. Late successional species (such as trees) will not become established until the environment has been suitably modified by the previous stages. This is crucial to a biological control strategy. Maintaining the area in an early successional stage will prevent the development of an environment which will allow the establishment of trees on the right-of-way.

An examination of the field evidence of succession, however, does not support the hypothesis developed from Clements work. Drury and Nisbet (1973) severely criticized the concept of reaction. In many of the examples they cited, early and midsuccession stages suppressed the climax, delaying succession, not encouraging it. Furthermore, successions in the same area followed several pathways and did not necessarily result in the same climax community.

The Initial Floristic Composition theory, proposed by Egler in 1954, was the concept which most readily explained the evidence provided by Drury and Nisbet (1973). This theory, developed from Egler's investigations on rights-of-way vegetation dynamics, was a restatement of Gleason's (1926, 1927) ideas on the individualistic nature of succession and the plant association. The soil is continually receiving and storing plant propagules. When a disturbance causes an opening, vegetational development proceeds from this propagule bank with little or no input from later sources. Thus species characteristic of both the pioneer and climax stages are present on the site from the onset, and the apparent change in species composition observed through time is due to the differential growth and longevity of the species involved.

Connell and Slatyer (1977) refined Egler's (1954) concepts and proposed three mechanisms for the succession process: inhibition, tolerance and facilitation. In the inhibition model, an existing

individual suppresses the growth of potential invaders (and other existing individuals). It is only following the death of the existing individual that an invader is able to occupy the site. If this invader is a member of the same species, no net change will occur. If the invader is a different species, there will be a change in the community. As climax species tend to be longer lived but slower growing than pioneer species, there is a high probability of a successionary pattern from a species composition which resembles a pioneer community to that which resembles a climax community. In the tolerance model, any seedlings which are tolerant of the environmental conditions at that site can become established. Thus there is a progressive replacement of less tolerant by more tolerant species with time. The third model proposed by Connell and Slatyer (1977) (facilitation) is basically a renaming of the successional theory of Clements (1916) discussed above.

Although Connell and Slatyer (1977) presented the inhibition and tolerance mechanisms as two separate and experimentally testable theories, in practice it is very difficult to separate these models. The community will inhibit invaders, and the invaders must be tolerant of existing conditions, thus on the surface it appears that these models reflect differing viewpoints of the same process. It is inhibition if you are discussing the existing community, and tolerance if you are discussing the future community. The major difference in the models concerns the mechanism in which space is released for colonization. In the inhibition model, death of an individual is due to disturbance, disease or old age, and replacement at any stage of development can be by the same or different species (resulting in either stability, succession or recession). In the tolerance model, death of an individual is the result of competitive interactions, and the community will always progress towards a more tolerant species composition. Thus stability will not develop until the most tolerant composition is formed (Connell and Slatyer 1977).

The complexities of species interactions have in most cases failed to provide strong evidence for or against the tolerance, inhibition or facilitation models. Species removal experiments in recently abandoned old-fields have shown that facilitation is not important in that system (Armesto and Pickett 1986). Removal of the dominant species (ragweed) in a 2-year old community did not affect successional development, thus disproving the need for facilitation at this location. In an older community (7-year, dominated by goldenrod), removal of the dominant species allowed several new species to invade, and promoted the growth of existing suppressed individuals. The goldenrod community is normally stable for 10 to 20 years, thus the large shifts in species composition observed when this species was removed may indicate that this community can delay succession (inhibition model).

In a floodplain succession, Walker and Chapin (1986) observed both facilitatory and inhibitory interactions. Alder, a nitrogen-fixing tree, improved the soil conditions (facilitation). However, its presence also resulted in a competitive interaction which inhibited growth of invading species. In this situation, the inhibition was thought to be more important than the facilitation (Walker and Chapin 1986). Abrams and Scott (1989) have discussed how disturbances in Michigan forest communities can accelerate succession, again discounting facilitation processes.

The facilitation model may be important in the invasion of forests into grassland communities. In the forest-prairie boundary of Oklahoma, trees could not establish directly into a prairie grassland area, but were able to establish under an existing sumac canopy (Petranka and McPherson 1979). The herbaceous layer in the sumac patches was similar to that in the forest, and it was suggested that the shade cast by the sumac caused a change in herbaceous layer which facilitated tree establishment. However, more recent studies with sumacs growing on roadside rights-of-way showed no differential effect on tree invasion (Luken and Thieret 1987).

There is an additional shift in emphasis between the early successional theories (Clements 1916, Egler 1954) and the later hypothesis (Connell and Slatyer 1977). The early theories attempted to

explain the entire series, from the initial invasion of the disturbed surface to the development of the final stable community, as one unified process or model. Later theories have discussed succession as a plant by plant replacement, and thus have gone from the level of community organization to the level of the individual (Pickett *et al.* 1987). This shift is most evident in the work of Horn (1974), who was able to describe a forest canopy succession with a replacement probability matrix and the widely applied JOBOWA forest model of Botkin *et al.* (1972), which utilized environmental conditions, competition, species growth rates and survivorship curves in predicting the replacement of individual forest trees. The processes of facilitation, tolerance and inhibition should be used to describe the species turnover at any stage of succession, and are not mutually exclusive (Picket *et al.* 1987, Huston and Smith 1987).

These individualist approaches to succession emphasize the importance of life history attributes, such as reproductive output, seed size, dispersal, vegetative reproduction, timing of reproduction, growth rate, growth form, longevity, maximal size, and age at sexual maturity. Some of these traits are mutually exclusive, thus a tradeoff exists. The concept of a strategy has been used to describe traits which co-occur due to evolutionary pressures. Thus the mention of a pioneer species brings to mind certain characteristics, while a climax species possesses different traits. The traits which distinguish pioneer from climax species are the most widely accepted generalizations in ecological theory (Huston and Smith 1987)

MacArthur and Wilson (1967) formalized strategies with their r-K continuum. The r-strategists were adapted to exploit the open, low competition environments. They have a high colonization potential (small, widely dispersed seeds, reproduce at early ages) and a high growth potential. A large part of their growth is concentrated on reproductive effort (they produce many seeds), thus r-strategists tend to have a small maximum size and a short lifespan. The K-strategy is favoured in high density, extremely competitive locations. These species allocate a large part of their energy reserves onto competitive structures. Thus they tend to be large in size, long lived but slow growing. Minimal energy is put into reproduction (produce relatively few seeds) and this is often delayed until late in life. There is an inverse relationship between the life history traits which infer success in the early stages of a succession to those that infer success at later stages (Huston and Smith 1987). Pioneer species tend to follow an r-strategy, while climax vegetation is dominated by K-strategists.

Grime (1977) also developed a life history strategy classification, based on the recognition of two important factors in any environment, stress and disturbance. Stress is defined as the presence or absence of a environmental factor which results in a decreased growth rate, while a disturbance is a factor which actually destroys biomass. These two factors combine to produce four environmental extremes, and three plant strategies (ruderal, competitive and stress tolerant).

The presence of a high (or frequent) disturbance and low stress produces an environment which favours a ruderal (weedy) species. This is basically the r-strategist described above, with the added factor that the species avoids a competitive or stressful situation by immediately channeling its energy from vegetative to reproductive growth. A low disturbance-low stress situation results in a highly competitive environment. The competitive strategy consists of large, long lived plants, but with high potential growth rates. These plants respond to increased competition or stress by trying to outgrow the situation. The stress-tolerant strategy is favoured in an environment which has a high stress factor but low disturbance. This strategy incorporates long-lived plants with slow growth rates, low reproductive outputs and a poor competitive ability.

Life history traits have been incorporated into predictive successional models. Nobel and Slatyer (1980) proposed a series of "vital attributes" to describe a successionary trend. Vegetational development will be affected by the mode of arrival following the disturbance (through widely dispersed seeds, the seed bank, or vegetative regrowth), environmental conditions required by

these propagules (ruderal, competitive, stress-tolerant, or requirement for ameliorated conditions (facilitation model)) and the ability of the species to restock its propagules following the disturbance (time to reproductive age, lifespan of species, lifespan of propagule). With knowledge of these vital attributes, the current stage of succession and the degree of the disturbance, a general description of the vegetation development following the disturbance can be predicted for forest communities (Cattelino *et al.* 1979).

There may be an application of life history strategies or vital attributes to right-of-way management. With knowledge of the strategies utilized by the troublesome tree species, it should be possible to determine the characteristics of a successful competitor for the trees. It is then a matter of finding compatible species with these characteristics and evaluating their ability to control trees.

The individualist models describe succession on a probability of replacement basis. In contrast to these, Tilman (1985) has developed a generalized hypothesis, called the resource ratio hypothesis, in which succession can be predicted from the environmental conditions. This model is based on competition for light, a limiting soil resource (macronutrient, micronutrient or water) and the supply of those resources.

This theory, as it pertains to succession, is dependent upon a negative correlation between the soil resource and the light intensity at the soil surface. There will be a soil resource that limits growth. If the supply of that resource is increased, there will be an increase in growth. This larger biomass will intercept more light. Thus there will be a decrease in the amount of light at the soil surface, which will inhibit the establishment and growth of seedlings. Conversely, if the supply of the soil resource decreases, this will cause a reduction in biomass, an increase in the amount of light at the soil surface and an increase in the establishment and growth of new seedlings.

There is also a negative relationship between a plant's ability to compete for light and soil resources. (The capture of light requires above ground structures while capturing soil resources requires below ground structures. Biomass can only be allocated to one at the expense of the other.) At any point in time, growth of some species will be limited by light, while the others will be limited by the soil resource. The species which can reduce the limiting resource to its lowest level will competitively displace all other species. A directional change in the supply of the soil resource will lead to a successional sequence.

Tilman's model states that the course and rate of the succession may be manipulated by altering the resource supply rate. Simulation modelling by Huston and Smith (1987) have demonstrated that increasing the supply rate leads to a preferential increase in the dominance of the species with higher growth rates. As the existing groundcover has a competitive advantage over invading individuals, fertilization of the community in nutrient-limited areas may allow fast growing herbs or shrubs to outcompete slower growing tree species (although the overall rate of succession may be increased (Huston and Smith 1987)). Tilman (1987) has demonstrated that additions of nitrogen resulted in increased biomass, increased height and decreased light penetration in a Minnesota oak savannah. Fertilization of a 1 year old community in Texas allowed the annual stage to persist for at least 3 years (instead of its normal 1 year) while fertilization of an older perennial dominated community caused a increase in annual plants, partially reverting the succession (Carson and Barrett 1988). West (1987) reports that nitrogen fertilization (at a rate of 200-400 kg $ha^{-1}$) was sufficient to prevent the invasion of alder, reducing the density from 1.88 stems $m^{-2}$ to 0.0 stems $m^{-2}$ on rights-of-way in Washington state. Fertilization was deemed to be a successful control method, delaying the invasion of trees by at least 2 years (Whitney *et al.* 1987). Fertilization experiments have also altered the plant composition in tropical areas (Harcombe 1977). In this study, fertilization resulted in an increase in herbaceous biomass at the

expense of the woody biomass.

As illustrated by the preceding discussion, successional theory has generated a large volume of paper, some testable hypotheses but few firm conclusions. However, there appears to be some generalizations which are of interest to rights-of-way vegetation management. An existing community will inhibit the invasion and growth of seedlings (through either competition, allelopathy, pre-emption or herbivory). Manipulations which affect the community composition can alter the path and rate of succession. Although the final outcome of the succession may not be predictable or preventable, encroachment of trees could be slowed down with an effective biological control strategy. What remains to be demonstrated is what type of community should be on the right-of-way and what is the best way to maintain and propagate that community.

Cover cropping is one alternative to establishing a competitive vegetation throughout the entire right-of-way. The ultimate concern of rights-of-way management is to keep the right-of-way free of tall growing trees. Thus the ability of the cover crop to interfere with tree invasion and growth is paramount to the selection of an appropriate species. This was the primary emphasis placed on the literature search. (In a field situation, the inhibitory effects of competition, allelopathy and herbivory cannot be separated, therefore the general term interference will be used).

## 2.0 METHODS

Various data bases were searched, and Table 1 provides a listing of these databases and the keywords used in the search. The searches flagged a total of 774 items. Although the keyword search appeared to be rather selective, most of the papers identified did not provide any useful information. Scanning of the titles of these items indicated that 102 papers may be of interest. Full abstracts were requested for these papers which enabled the list to be narrowed down to 59 papers. A literature search directed towards the 33 species which Suffling recommended for cover crop testing in Ontario (Table 12 of Suffling 1979) did not uncover any papers on interference interactions with any tree species.

The pertinent information from these papers, plus any other relevant items which were uncovered during the course of this project, were summarized in tabular form. The information contained in the tables includes:

type of cover crop
method used to establish cover crop
persistence of the cover crop
tree species involved
age of trees at the start of the study
experimental control used
duration of experiment
location of experiment
growth of the control and treatment trees
effect of cover crop on tree growth (expressed as % growth of control)
size of experimental plots
number of replicates

The effectiveness of the cover crop (termed interference potential) was estimated for this review as the percentage change in growth of the target trees relative to the control. Thus a value of 100% represents no effect, values greater than 100% indicate the cover crop stimulated growth of the tree and values less than 100% indicates a inhibition of growth by the cover crop. This

Table 1

The data bases searched, keywords
used in the search and the number of items detected.

| Database Searched | Number of Items Detected |
|---|---|
| BIOSIS (1969-89)<br>AGRICOLA (1979-89)<br>CAB (1984-89)<br>ENVIRONLINE (1970-88) | 172 |

Keywords Used:

Tree or Acer or conifer or willow or poplar or Rosaceae or Betulaceae or Fagaceae or Malaceae or Oleaceae or apple or Pinus or pine or Picea or spruce or maple or Fagus or Beech or Quercus or oak or Fraxinus or ash or Populus or Prunus or cherry or peach or apricot or Malus AND (ground or cover or smother or companion) AND (crop or species) AND interference or competition or allelopathy or inhibition.

| Database Searched | Number of Items Detected |
|---|---|
| BIOSIS (1969-89)<br>AGRICOLA (1979-89)<br>CAB (1984-89)<br>COMDPENDEX PLUS | 69 |

forest or forestry or wood or woodlot or woodland or tree AND succession or establishment or regeneration or reforestation

| Database Searched | Number of Items Detected |
|---|---|
| BIOSIS<br>AGRICOLA<br>CAB | 309 |

Suffling's List of 33 (Table 12 in Suffling 1979) AND Competition

| Database Searched | Number of Items Detected |
|---|---|
| DOE (1974-89)<br>Electric power database (1972-89)<br>CODPENDEX PLUS ( 1970-89) | 127 |

Right(s)-of-way AND vegetation or revegetation or cover crop or ground cover

may not be the best measure of interference effects, but does allow for general comparisons of the same cover crop over several papers. The actual growth of the treatment and control trees is also presented. Whenever possible this was presented as an annual increase in growth (final - initial/duration of experiment). For papers which reported that a treatment had "no effect on growth", but did not provide data, the interference potential of the cover crop was arbitrarily recorded as 100%.

The actual parameter used to measure growth varied with each paper. Common measurements included height, diameter, density, and biomass, while some of the less common measurements included fruit yield and canopy volume. In papers where more than one measure was used, each is presented in Appendix B, C and D, while only the measure most affected by the interference was used in the statistical analysis (Table 2).

No attempt was made to include a variance or standard error for the growth measurements. When the papers included a statistical analysis, the probability that the treatment differs from the control is given in Appendix B, C, or D. It is customary in statistics to use a $p = 0.05$ as the value to delineate significant from nonsignificant results. Thus if $p <= 0.05$ the cover crop had an effect on growth, while if $p > 0.05$ it did not. When no specific probability level was given, "n" was recorded if the paper said there was no effect, and "y" was recorded if the paper said there was an effect. A "?" designates that no indication of a statistically significant effect was given in the paper. In papers which included a comparison of several cover crops, the interference potential of the crops could be ranked from best to worst using a multiple range test. Thus a rating of "1 out of 5" indicates that particular cover crop was the most inhibitory of the five groupings identified by that paper.

Critical to this analysis is the choice of a control. As most of the studies included a non-competitive, bare ground treatment, this was chosen as the reference point. As indicated in Appendices B, C, and D, there was considerable variability as to how this bare ground control was achieved, ranging from continual weeding, to application of various herbicides or mulches. For those papers which did not include a bare ground control, but contained a comparison to natural vegetation, this was used as the control. Growth of the trees is expected to be highest in the no competition, bare ground situation. Thus use of a natural vegetation control will make the competitive effects smaller than a bare ground control. It should be argued that we are interested in the effect of a cover crop relative to the natural right-of-way vegetation, thus a natural vegetation control should be more appropriate than bare ground. However, in a survey to determine the relative effect of a potential cover crop candidate, it is more important to standardize the data to a uniform control than a highly variable one.

Statistical analysis involved the use of the nonparametric Kruskal-Wallis Analysis-of Variance (ANOVA) and the Mann-Whitney test. The ANOVA is used to analyze an experimental data set which involves multiple treatments (*ie.* cover crops). The ANOVA will indicate if one or more treatments has a different effect on the measured parameter (*ie.* the interference potential). However, this ANOVA does not provide an error estimate or allow for a multiple range test to indicate which treatments are different. The Mann-Whitney test is designed to compare two treatments. This was used to compare the interference potential of each cover crop to that of the natural vegetation.

A complete list of the species mentioned in this report is included as Appendix A.

## 3.0 RESULTS

### 3.1 The interference effects of various cover crops

The main body of the literature is summarized in three appendices. Appendix B is a summary of 30 papers which involved an experimental comparison of interference between one or more defined cover crops and a target tree species. They are arranged alphabetically according to the cover crop. The interference potentials are highly variable, and are displayed as a frequency histogram in Figure 1. The effects of the cover crops ranged from total inhibition of tree growth (0% of the bare ground control) to a maximal stimulation of 4500%. The majority of interactions were inhibitory in nature.

Natural vegetation was also found to inhibit tree growth relative to the bare ground control. Twelve papers included a comparison of either an undefined natural or slightly manipulated native vegetation to a bare ground situation (Appendix C, Figure 1b). An additional 12 papers contained observational data only, and these are summarized in Appendix D. The natural vegetation resulted in an interference potential of $56\pm23\%$ (mean$\pm$SD).

Most papers identified crops which were more inhibitory than the natural vegetation. In Figure 1, there is a higher proportion of cover crops which recorded an interference potential between 0 and 20% than natural vegetation types. However, there was no overall statistical difference between the interference potential of the cover cropped and the naturally vegetated ground (Mann-Whitney test, $Z = 0.1338$, $p = 0.89$), which indicates that only a limited number of cover crops may be more effective in inhibiting the establishment or growth of trees.

The results of the ANOVA are presented in Table 2. For this procedure, the data from Appendix B, C, and D were combined, and multiple growth measurements for the same experiment were eliminated, leaving a data set of 68 species and 177 entries. The interference potentials were then ordered from low to high, ranked from 1 to 177, and the mean rank for each species was calculated. There is a significant species effect (test statistic = 114.159, $p$=0.003896).

The majority of the species were used in fewer than 3 studies, thus provided little concrete information. Species in Table 2 which are in bold type occur in 3 or more studies, while the natural vegetation groups (natural, grass, forb and shrub) are indicated with an asterisk. The natural vegetation class was listed as the 29th most inhibitory groundcover, with a mean ranking of 77 (Table 2). Hayscented fern (mean rank 32), tall fescue (51), New York fern (61), Bermuda grass (63) and mixtures containing red fescue (46) appear to have a higher interference potential, while short husk grass (99), white clover (109), orchard grass (110), shrubs (158) and ceanothus (159) stimulated tree growth relative to natural vegetation. Only hayscented fern ($Z = -2.643$, $p = 0.0082$), shrubs ($Z = 2.28477$, $p = .0223$), and ceanothus ($Z = 2.0241$, $p = .0429599$) were significantly different from the natural vegetation (as indicated by the Mann-Whitney test). The lack of cover crops which are significantly more inhibitory than the natural vegetation is discouraging, but not surprising considering the small sample size and high variability in the experimental conditions of the different studies.

It is generally thought that the competitive ability of a plant is related to its size (Gaudet and Keddy, 1988). In this review, there was no significant correlation between the height of the cover crop species and its interference potential ($r_s = 0.0015$, $p = 0.9871$).

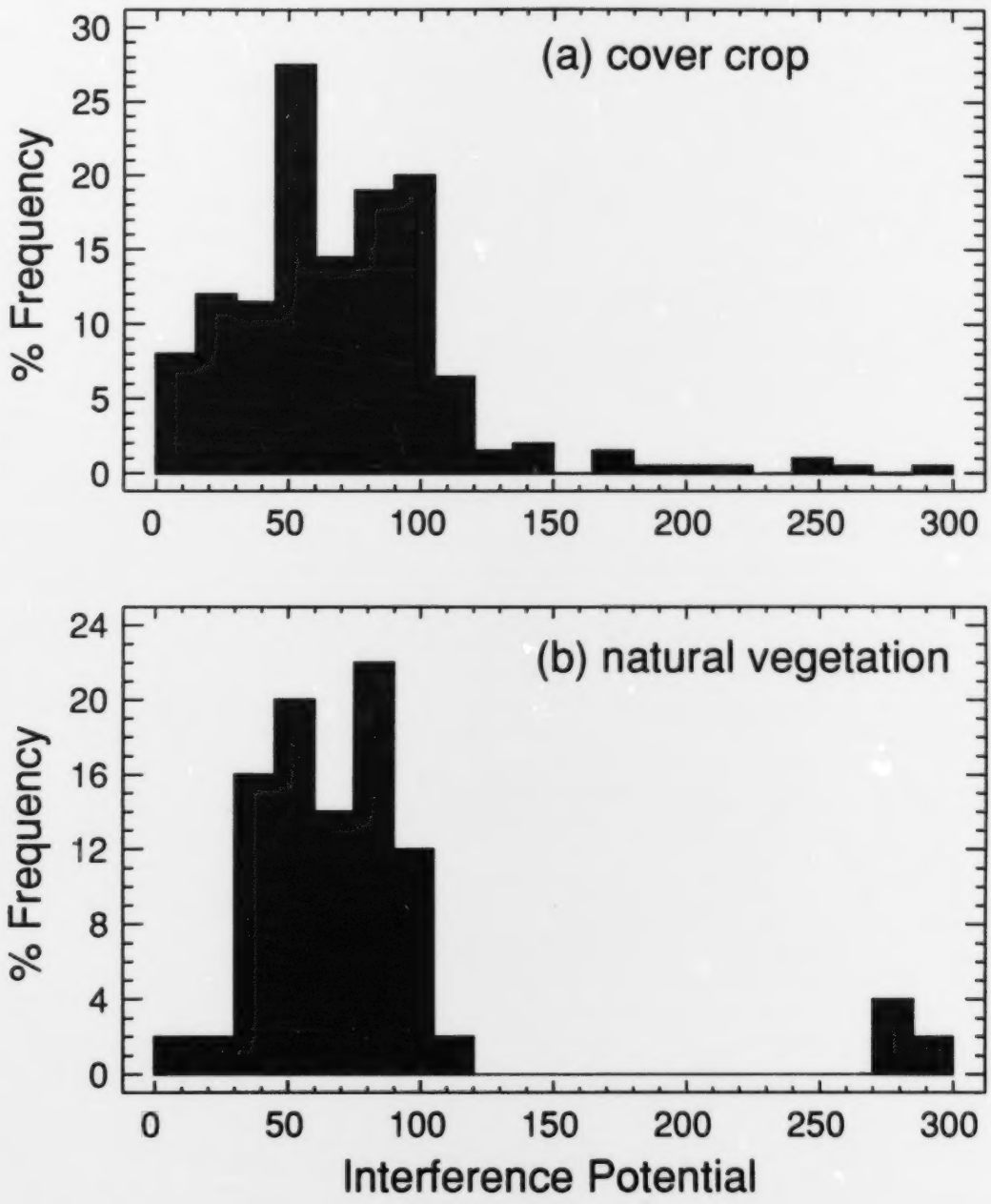


Figure 1: A frequency histogram of the interference potential of the cover crops listed in Appendix B, C, and D
(a) cover crop (b) natural vegetation

Table 2: Kruskal-Wallis ANOVA ranking the cover crop species on their ability to interfere with the growth of trees.

| Species | sample size | Mean rank sum | Species | sample size | Mean rank sum |
|---|---|---|---|---|---|
| brome grass | 1 | 3 | red alder | 1 | 96 |
| greenbrier | 1 | 3 | **short husk grass** | **4** | **99** |
| birdsfoot trefoil | 1 | 6 | **clover, white +** | **4** | **100** |
| quackgrass | 1 | 7 | wheatgrass, crested | 1 | 100 |
| huckleberry | 1 | 8 | greenleaf manzanita | 2 | 101 |
| vetch, crown | 1 | 13 | orchard grass + | 2 | 106 |
| blueberry, low late | 1 | 16 | **clover, white** | **4** | **109** |
| alfalfa + | 1 | 20 | bluegrass, Kentucky | 2 | 110 |
| brome grass + | 1 | 20 | **orchard grass** | **5** | **110** |
| fescue, rough + | 1 | 20 | red sorrel | 2 | 110 |
| wheatgrass, crested + | 1 | 20 | oatgrass, tall | 1 | 112 |
| Calamagrostis rubescens | 1 | 25 | Korean lespedeza | 2 | 113 |
| fescue, Arizona | 1 | 27 | bamboo, dwarf | 2 | 119 |
| **hayscented fern**** | **8** | **32** | grass + shrub | 1 | 121 |
| raspberry | 2 | 35 | clover, red + | 2 | 123 |
| ceanothus and forbs | 2 | 43 | clover, yellow sweet | 1 | 125 |
| **fescue, red +** | **4** | **46** | nimbleweed | 1 | 129 |
| Bahiagrass | 1 | 48 | squirrel tail | 1 | 130 |
| **fescue, tall** | **4** | **51** | burnet, small | 2 | 131 |
| mountain muhly | 1 | 53 | wheat | 1 | 131 |
| **New York fern** | **4** | **61** | blackberry, trailing | 1 | 137 |
| **Bermuda grass** | **5** | **63** | blue gramma | 1 | 142 |
| Ivy, English | 2 | 67 | yarrow | 1 | 144 |
| **ryegrass, perennial +** | **4** | **67** | wood sorrel | 1 | 146 |
| **bluegrass, Kentucky +** | **7** | **70** | fescue, hard | 1 | 150 |
| **bent grass, common** | **3** | **75** | red top | 1 | 150 |
| **timothy +** | **6** | **75** | wheatgrass, pubescent | 1 | 150 |
| **club moss** | **6** | **76** | ryegrass, Italian | 1 | 153 |
| *** natural** | **11** | **77** | *** shrub**** | **4** | **158** |
| fescue, red | 2 | 79 | **ceanothus**** | **3** | **159** |
| ryegrass, perennial | 2 | 81 | vetch, nova | 1 | 160 |
| timothy | 2 | 83 | plantain | 1 | 162 |
| ragweed | 1 | 86 | vetch, hairy | 2 | 169 |
| fescue, sheep + | 1 | 89 | partridge berry | 2 | 170 |
| **meadow grass, rough +** | **3** | **90** | clover, crimson | 2 | 173 |
| *** forbs** | **5** | **92** | yuchi clover | 1 | 173 |
| *** grass** | **7** | **93** | clover, subterranean | 1 | 175 |
| liriope | 2 | 93 | sumac | 1 | 177 |
| bluegrass, big | 1 | 95 | | | |

Kruskal-Wallis test statistic = 114.159, $p = 0.003896$
Species occurring in more than 2 papers are in bold type
+ indicates the species was used in a mixture
* indicates a naturally occuring vegetation. Any cover crop appearing above these are more inhibitory than the natural vegetation.
** significantly different from natural vegetation class (Mann-Whitney test, $p < 0.05$)

## 3.2 Problems with the studies

It is very difficult to provide a detailed breakdown of each paper represented in the appendices, since they vary considerably in their experimental design. Some of the parameters are listed in Appendix B, C, and D (age of tree, duration of experiment), while other, equally important parameters (location, method of cover crop establishment, plot size, number of replicated plots, purpose of the experiment, success in establishing and maintaining the cover crop and bare ground controls) are summarized in Tables 3, 4 and 5. The following is a general discussion of the papers.

*Objectives of the Studies*: The primary objective for most of the studies was to increase the growth of trees. Seven exceptions were the right-of-way fertilization experiment of West (1987), the observational reports of Bramble and Byrnes (1976), Suffling (1979), Pound and Egler (1953), Niering and Goodwin (1974) and Niering *et al.* (1986) and a range conversion experiment by Bailey (1972). It is expected, therefore, that there will be a bias in the choice of cover crops towards the poor competitors. Only half (27) of the papers included a proper experimental evaluation of the interference potential of the groundcover and the best of these are directed towards the orchard industry. Twelve papers were natural release studies (primarily using herbicides), while 13 papers could be classified as observation or correlation studies. The release experiments may be useful, as they provide an indication of the general effects of a natural groundcover. The observational studies are only useful in suggesting species for future experimental considerations.

*Lack of multiple comparisons*: The ideal paper for our purposes is one which compares several different crops. Only 13 of those cited involved a comparison of 2 or more cover crops. An additional 4 papers reported 2 or more different natural groundcovers, but these were primarily observational studies.

*Location of studies*: The only studies undertaken in an area with vegetation and climate comparable to Ontario are the observational studies of Bramble and Byrnes (1976), Niering and Goodwin (1974), Niering *et al* (1986), Horsley (1977), and Sharp *et al.* (1980), the release experiments of Horsley (1981), Baskerville (1961), and Lambert *et al.* (1972), the cover crop experiment of McLaughlin *et al.* (1985) and the report of Suffling (1979) (Table 3). Most of the other studies were conducted in the forest areas of the west coast and the Rocky Mountains.

*Target tree species*: The location of the studies also results in a selection of target trees uncommon to Ontario. Conifers constitute the majority of the trees studied, while the hardwood trees problematic for Ontario Hydro are very under-represented (Table 4). The majority of the trees used in these experiments are young transplants (Appendix B, C and D), thus the ages are comparable to those trees expected to occur on rights-of-way undergoing 4 to 6 year treatment cycles. The use of transplants, instead of seeding the trees, means that the experiments will measure the interference of growth, not of establishment. The studies which used tree seeds (Buckley *et al.* 1981, Buckley 1985) had extremely low germination in both treatment and controls, while Shribbs *et al.* 1986 used pregerminated seeds in a greenhouse experiment.

*Duration of experiment*: The majority of the experiments were of short duration (19 studies of 1 or 2 years, only 2 longer than 5 years) (Appendix B, C, and D). This is realistically much too short to determine a growth effect on tree species or to provide any indication of the longevity of the cover crop itself.

Table 3: The source of the studies sited in Appendix B, C and D and some of the experimental conditions in those studies.

| Code | Source | Establishment Method | Location of Experiment | Number of[1] Crops | Reason[2] for Study | Plot Size |
|---|---|---|---|---|---|---|
| 1 | Bailey 1972 | Disc and Drill seed | Alberta | 1 | experiment | 1.6 ha |
| 2 | Bailey & Gupta 1973 | greenhouse experiment | | 1 | experiment | pots |
| 54 | Balneaves 1982 | no details provided | New Zealand | natural | release | ? |
| 3 | Baron 1962* | burned | California | 8 | experiment | 12x24m |
| 4 | Baskerville 1961 | natural community | New Brunswick | natural | release | 1m |
| 5 | Bould & Jarrett 1962 | cultivated | England | 3 | experiment | pots |
| 6 | Bramble & Byrnes 1976 | natural community | Pennsylvania | RoW | observation | 0 |
| 7 | Brown, 1980 | no details provided | ? | natural | release | ? |
| 8 | Buckley *et al.* 1981 | established lawn | England | lawn | release | .3x.3m |
| 9 | Buckley 1984 | no details provided | England | 6 | experiment | 1mx2m |
| 10 | Coffman 1975 | natural community | New Mexico | natural | correlation | |
| 11 | Cole and Newton 1987 | no details provided | Oregon | 2 | experiment | variable |
| 12 | Devonald 1986 | natural community | England | lawn | release | .45x.45m |
| 13 | Eissenstat & Mitchell 1983 | clearcut, hand seeded | Idaho | 1 | experiment | .1 ha |
| 14 | Elliott & White 1987 | no details provided | Arizona | 6 | experiment | 3x3m |
| 15 | Fales and Wakefield 1981 | natural community | Rhode Island | lawn | experiment | .45x.45m |
| 16 | Fisher and Adrian 1981 | greenhouse experiment | Florida | 1 | experiment | pots |
| 17 | Gordon 1962* | natural community | California | natural | release | 4x4m |
| 18 | Haines *et al.* 1978 | no details provided | Alabama | 5 | experiment | 2.25x2.25 |
| 19 | Horsley 1977 | natural community | Pennsylvania | | correlation | |
| 20 | Horsley 1981 | natural community | Pennsylvania | natural | release | 7.6x7.6m |
| 21 | Kennedy 1981 | | Mississippi | natural | release | 20x20m |
| 22 | Lambert et al. 1972 | cultivated | Wisconsin | natural | release | 15x30 |
| 23 | Larson and Schubert 1969 | no details provided | Arizona | 2 | experiment | ? |
| 24 | Maguire & Forman 1983 | natural community | West Virginia | natural | observation | .3x.3 m |
| 25 | McLaughlin *et al.* 1985 | plowed and disced | Wisconsin | 1 | experiment | 15x15 m |
| 26 | Niering *et al.* 1986 | natural community | Connecticut | natural | observation | |
| 27 | Niering & Goodwin 1974 | natural community | Connecticut | natural | observation | |
| 28 | Petersen 1988 | natural community | Montana | natural | release | 6x32m |
| 29 | Petersen & Newton 1982* | natural community | Oregon | natural | release | ? |
| 30 | Petranka and McPherson 1979 | natural community | Oklahoma | natural | correlation | 15 |
| 31 | Pound & Egler 1953 | natural community | New York | RoW | observation | |
| 32 | Rejmanek & Messina 1988 | natural community | California | natural | correlation | ? |
| 33 | Rogers *et al.* 1948 | no details provided | England | 3 | experiment | 15x15m |
| 34 | Shainsky & Radosevich 1986 | natural community | California | natural | experiment | 18x18m |
| 35 | Sharp et. al 1980 | no details provided | Pennsylvania | RoW | correlation | |
| 36 | Shoup & Whitcomb 1981 | greenhouse experiment | greenhouse | 3 | experiment | pots |
| 37 | Show 1927 | natural community | California | natural | observation | |
| 38 | Shribbs *et al.* 1986 | greenhouse experiment | greenhouse | 4 | experiment | pots |
| 39 | Shribbs & Skroch 1986 | no details provided | North Carolina | 9 | experiment | 4.5x4.5m |
| 41 | Stott 1976 | no details provided | England | 2 | experiment | ? |
| 42 | Suffling 1979 | Right-of-way | Ontario | RoW | observation | |

(continued on next page)

Table 3 (continued)

| Code | Source | Establishment Method | location of Experiment | Number of[1] Crops | Reason[2] for Study | Plot Size |
|---|---|---|---|---|---|---|
| 43 | Todhunter & Beineke 1979 | natural community | Indiana | natural | release | 1.2x1.2m |
| 44 | Wahlenberg 1930 | natural community | Montana | natural | experiment | ? |
| 45 | Walters & Gilmore 1976 | greenhouse experiment | greenhouse | 1 | experiment | pot |
| 46 | Warren *et al.* 1987a | no details provided | North Carolina | natural | experiment | ? |
| 47 | Warren *et al.* 1987b | greenhouse experiment | greenhouse | 2 | experiment | pot |
| 49 | Weller *et al.* 1985 | ploughed and tilled | North Carolina | 1 | experiment | 1.2x1.2m |
| 50 | West 1987 | Right-of-way | Oregon | Row | experiment | 7x7m |
| 51 | Whitcomb 1981 | no details provided | Oklahoma | 1 | experiment | 1.35x1.35 |
| 52 | Youngberg *et al.* 1979* | natural community | Oregon | natural | correlation | 2x2m |
| 53 | Zutter *et al.* 1986 | roller drum chopper | Alabama | natural | release | 25x25m |

* Cited by Stewart *et al.* 1984

1 'natural' indicates that only the natural vegetation was manipulated
'lawn' indicates that vegetation studied was a mowed lawn
'RoW' indicates that the study was on a right-of-way

2 'experiment' designates a study of planted crops
'release' indicates a study where existing vegetation was removed
'observation' indicates the study was strictly an observation account of natural plant distributions
'correlation' indicates an experimental design statistically relating the natural distribution of plants

Table 4: A breakdown of the tree species used for targets indicating the type of study and reference source for each.

| Target Tree | Type of cover crop | | | | | | | | | | | Total Studies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Defined Cover Crop | | | | | Natural Vegetation | | Field Observations | | | | |
| alder, red | | | | | | 50 | | | | | | 1 |
| apple | 5 | 33 | 38 | 39 | 41 | | | | | | | 5 |
| ash | 8 | | | | | | | | | | | 1 |
| ash, green | | | | | | 21 | | | | | | 1 |
| ash, white | | | | | | | | 42 | | | | 1 |
| aspen, trembling | 1 | 2 | | | | | | | | | | 2 |
| beech | | | | | | 12 | | | | | | 1 |
| birch | 9 | | | | | | | 24 | 42 | | | 3 |
| cherry, black | 20 | | | | | | | 19 | 24 | | | 3 |
| chinese juniper | 51 | | | | | | | | | | | 1 |
| cottonwood | 36 | | | | | 21 | | | | | | 2 |
| Douglas fir | 11 | 13 | 29 | | | 11 | 29 | 10 | 32 | 52 | | 8 |
| dwarf holly | 51 | | | | | | | | | | | 1 |
| fir, balsam | 4 | | | | | | | | | | | 1 |
| fir, fraser | 47 | | | | | 7 | 46 | | | | | 3 |
| hemlock | | | | | | | | 24 | | | | 1 |
| Japanese black pine | 51 | | | | | | | | | | | 1 |
| maple, Norway | 8 | | | | | | | | | | | 1 |
| maple, red | 1 | | | | | | | 19 | | | | 2 |
| maple, silver | 36 | | | | | | | | | | | 1 |
| maple, sugar | | | | | | 19 | 42 | | | | | 2 |
| maple, sycamore | 9 | | | | | | | | | | | 1 |
| oak, nuttall | | | | | | 21 | | | | | | 1 |
| peach | 49 | | | | | | | | | | | 1 |
| pecan | | | | | | 21 | | | | | | 1 |
| pine | | | | | | 17 | | | | | | 1 |
| pine, loblolly | | | | | | 53 | | | | | | 1 |
| pine, ponderosa | 3 | 14 | 23 | 28 | 34 | 14 | | | 32 | 37 | | 8 |
| pine, radiata | | | | | | 53 | | | | | | 1 |
| pine, red | 22 | | | | | | | | | | | 1 |
| pine, scots | | | | | | 1 | | | | | | 1 |
| pine, slash | 7 | | | | | | | | | | | 1 |
| pine, sugar | | | | | | | | 37 | | | | 1 |
| pine, yellow | 44 | | | | | | | | | | | 1 |
| poplar, hybrid | 25 | | | | | | | | | | | 1 |
| sequoia | | | | | | | | 37 | | | | 1 |
| spruce, Norway | 1 | | | | | 46 | | | | | | 2 |
| spruce, white | 4 | | | | | | | | | | | 1 |
| sweetgum | 45 | | | | | 21 | | | | | | 2 |
| sycamore | 18 | | | | | 21 | | | | | | 2 |
| walnut, black | 43 | | | | | | | | | | | 1 |

See Table 3 for references.

Table 5: An indication of the degree of establishment and persistence of the various cover crop species used.

| Competing Species | Duration of Experiment | Reference[1] |
|---|---|---|
| *Crops with good establishment and persistence* | | |
| Bermuda grass | 2 | 51 |
| blackberry, trailing | 4 | 39 |
| blue grass, kentucky | 4 | 39 |
| brome grass + | 3 | 1 |
| burnet, small | 4 | 9 |
| crimson clover | 4 | 18 |
| fescue, red | 4 | 9 |
| fescue, red + | 3 | 1 |
| fescue, tall | 4 | 39 |
| Korean lespedeza | 4 | 39 |
| nimbleweed | 4 | 39 |
| orchard grass | 4 | 39 |
| orchard grass + | 6 | 33 |
| orchard grass + | 3 | 13 |
| red sorrel | 4 | 39 |
| ryegrass, perennial | 5 | 5 |
| subterranean clover | 4 | 18 |
| timothy | 5 | 5 |
| timothy + | 3 | 13 |
| vetch, hairy | 4 | 18 |
| vetch, nova | 4 | 18 |
| wheat | 4 | 39 |
| yarrow | 4 | 9 |
| yuchi clover | 4 | 18 |
| *Crops with poor initial establishment but persistent* | | |
| orchard grass | 2 | 14 |
| wheatgrass, crested | 2 | 14 |
| *Crops with good establishment but not persistent* | | |
| birdsfoot trefoil | 4 | 25 |
| clover, red + | 6 | 33 |
| clover, white | 4 | 9 |
| clover, white | 5 | 5 |
| plantain | 4 | 9 |
| quackgrass | 4 | 25 |
| ragweed | 4 | 39 |
| ryegrass, Italian | 4 | 9 |
| *Crops with poor establishment* | | |
| alfalfa + | 3 | 1 |
| clover, red + | 3 | 13 |
| fescue, rough + | 3 | 1 |
| wheatgrass, crested + | 3 | 1 |

1 See Table 3 for references
+ indicates that the species was part of a mixture

*Establishment of cover crop*: The methods used to establish the cover crop were quite variable (Table 3). Several papers did not provide any indication of the site preparation or seeding method. A factor critical to the results is the time interval between planting of the cover crop and planting of the tree. A crop that is well established prior to the start of the interference measurements should have a more inhibitory effect than one seeded in simultaneously or following tree planting. This may help explain the general 50% inhibition observed for the natural groundcovers, which had a large head start. Most of the multiple cover crop experiments had the crop established at the same time or following tree planting.

Persistence and degree of establishment was also highly variable. This has been summarized in Table 5. Few authors reported on the establishment or persistence of the cover crops they tested. Red and white clover appear to be poor choices for cover crops, as they are nonpersistent. Orchard grass appears most often in the persistent category. Several of the crops tested were not monocultures. In the appendices, the compone: ts of mixtures have been reported individually. A "+" used to indicate that entry originated from a species mixture. It is impossible to determine the effectiveness of each component, thus entries marked with a "+" should be downweighed.

*Measurement of growth*: Several different measurements of growth have been used in these studies. Table 6 provides a summary of the interference effects averaged over all the cover crops for the 6 most frequently used growth measurements. These means ranged from 56% when dry weight was used as a measure of growth to 176% when canopy volume was used. Diameter is more affected by interference than height, while survival was unaffected by the groundcover. Some of these discrepancies can be explained, and are probably artifacts of short duration experiments.

Table 6

A summary of the different growth measurements
used to estimate interference in the literature.

| Measured parameter | Interference Mean | Potential SE | Sample Size |
|---|---|---|---|
| dry weight | 56.17 | 7.79 | 24 |
| diameter | 57.35 | 6.19 | 48 |
| density | 72.99 | 17.32 | 32 |
| height | 84.51 | 9.24 | 68 |
| survival | 102.96 | 15.32 | 34 |
| canopy volume | 176.18 | 19.35 | 11 |

Height appears to be less affected by interference than weight and diameter. The trees studied are primarily transplants. There is a tendency of a transplanted tree to partition a disproportionate amount of growth in its first few years to root rather than shoot growth (Larson and Schubert 1969). In addition, height growth in many tree species is determinant (*ie.*, last year's growing conditions determine this year's growth). Thus you should not observe an effect on height until the second year of an experiment for many tree species, whereas weight and diameter will be immediately affected. Thirdly, when placed in a competitive situation, a tree has only two responses: tolerate the competition (and hope the competitor dies before it does) or

attempt to outgrow the situation. In both cases, weight increases will be affected by the competition, while in the latter, growth will be directed towards height instead of diameter. The later option may also help explain why canopy volume was stimulated by interference.

Survival, as a growth measure, can only be used for established individuals or germination of a known amount of seeds. It is unlikely that in the short term, competition will result in the death of an established tree. Thus in this situation, survival is more a measure of transplant success or seed viability than interference.

### 3.3 The mechanism of interference

In a field situation it is difficult to determine the relative importance of the various interference mechanisms. This has not, however, prevented researchers from speculating, and some have adopted experimental designs to test for a specific mechanism.

Allelopathy has been implicated in forest regeneration failure (Fisher 1980) and it may be an important component of the interference ability of some species (Horsley 1977, Fales and Wakefield 1981).

Competition for space has been suggested in three studies. Walters and Gilmore (1976) and Buckley (1984) reported that pre-emption decreased germination, and Whitney *et al.* (1987) suggested that the build-up of a thick sod or litter lay may inhibit establishment.

Shading may be important in seedling establishment, especially with conifers, but many hardwood species have sufficient seed resources to allow them to germinate and to grow through the dense groundcover. In harsher environments and drought situations, the alleviated microclimate resulting from the shading may actually increase the chances of survival (Wahlenberg 1930, Coffman 1975, Pook 1979).

Grazing is often overlooked as a factor in interference. A cover crop provides a different food source than the native vegetation, and attraction of more herbivores to the area may result. Popko (1973) and Horsley (1977) estimate that 15 to 78% of tree seedlings and saplings are grazed.

The majority of the papers cited competition for nutrients or moisture as a major factor in interference. Trees growing with a cover crop have shown nutrient deficiencies (Rogers *et al.* 1948, Kennedy 1981, Shribbs and Skroch 1986). The addition of fertilizers decreased the interference potential of the cover crop in may cases (Bould and Jarrett 1962, Fales and Wakefield 1981, Balneaves 1982, McLaughlin *et al.* 1985, Shribbs *et al.* 1986) suggesting that nutrient competition was a major mechanism in the interference. However, other studies have shown that fertilization alleviated the deficiencies without increasing tree growth (Rogers *et al.* 1948, Kennedy 1981) and many observed an increase in the interference potential of the cover crops when they were fertilized (Harcombe 1977, Fisher and Adrian 1981, Balneaves 1982, Shribbs and Skroch 1986, West 1987, Whitney *et al.* 1987).

Low soil moisture or decreased leaf water potential in the cover-cropped trees have been observed by many investigators (Wahlenberg 1930, Coffman 1975, Brown 1980). Irrigation resulted in a decreased interference potential in studies by Larson and Schubert (1969), Fisher and Adrian (1981) and Lambert *et al.* (1972). Kennedy (1981) was the only study which failed to see an increased moisture stress in the cover-cropped plots.

Interpretation of irrigation or fertilization experiments is difficult. The new resources are available to both the cover crops and the tree, thus the outcome is dependent upon the relative

responses of both. As mentioned before, the experiments discussed above are primarily of short duration (Appendix B, C, and D). Thus the results more likely reflect a transitory response instead of the final, stabilized condition.

## 4.0 DISCUSSION

### 4.1 The use of cover crops on utility rights-of-way

The ability of a vigorously growing ground cover to inhibit the establishment of trees has been well documented (Pound and Egler 1953, Niering and Egler 1955). This information has been put into practice when herbicide applications shifted from broadcast to selective spraying techniques to encourage a more resistant groundcover. Numerous studies have investigated the effectiveness of this change (Niering and Goodwin 1974, Carvell 1976, Bramble and Byrnes 1983, Bramble *et al.* 1984, Jotcham 1985, Dreyer and Niering 1986, MacLellan and Stewart 1986), but the development of a stable groundcover has been a highly elusive goal (Jotcham 1985). Unfortunately, there have been few investigations aimed at extending this biological control strategy to its obvious endpoint, the direct replacement of an easily invaded natural groundcover with a cover crop more resistant to invasion.

Published reports on the use of cover crops in the utility industry are rare. Arner (1960, 1966) has been instrumental in initiating some cover cropping in the south-east United States. The primary emphasis of these projects has been to increase the wildlife usage of the rights-of-way, thus the selection of crops has been highly slanted towards quail and deer foods. Arner (1960) estimated the costs of various maintenance options in Alabama to be \$65 to \$ 90 per acre for foliar herbicide (3 to 6-year cycles), \$45 to \$85 for basil herbicides (3 to 6 year cycle), hand cutting at \$18 to \$59 (3-year cycle) and mechanical cutting at \$12 to \$60 (3 year cycle). In Maryland, a shift from herbicide treatment to a cover cropping approach reduced the maintenance cost from \$14 to \$7.50 per acre (Arner 1966). No information was provided beyond the estimated cost savings on the resistance to tree invasion for the cover crops tested in these studies.

The Tennessee Valley Authority uses a combination of cover cropping and mowing to control their rights-of-way. The planting of cover crops on a newly established right-of-way reduced the total tree density from 14,000 stems per ha to 7,200 stems per ha in the three years following clearing (Allsbrooks *et al.* 1984). The total plant biomass on the cover cropped and control rights-of-way were similar for each year of the study, thus the reduction in tree density was due to a cover crop effect or an interaction between cover cropping and the mowing regime.

In 1969, "Ontario Hydro began an extensive evaluation program to determine what grasses, legumes and natural shrubs could be seeded directly, in order to control tree growth in new and existing rights-of-way." (Gillespie 1978). Some information is available on the initial establishment and wildlife usage of these experimental plots (Popko 1973, Osmars 1975), however, little quantitative data is available on the effect of the crops on tree invasion. An estimate of maintenance times for a cover cropped (5 miles per week) and uncropped (3.75 miles per week) rights-of-way has been presented by Gillespie (1978). This suggests that the cover cropped right-of-way contained fewer incompatible trees.

Suffling (1979) provided a more extensive review of Ontario Hydro's cover crop program. Although he found several problems in the experimental design (lack of controls and an insufficient number of replicated, multicrop comparisons), he was able to conclude that cover cropping was "generally more effective in brush control than either blanket foliage sprays or selective cutting."

The competitive ability of natural right-of-way vegetation may also be increased with fertilization (West 1987, Whitney *et al.* 1987). This is another option available in the biological control strategy which should be investigated along with the cover crops.

There appears to be a contradiction between the studies of Suffling (1979), Gillespie (1978) and Allsbrooks *et al.* (1984), which suggest that cover crops can be effective on the rights-of-way, and the general conclusion reached from the analysis in Table 2 that very few species differ from a natural ground cover in their interference ability. This contradiction has its roots in the site specificity of the various studies. Many of the investigations summarized in Appendix B, C, and D identified a cover crop which was more inhibitory to tree growth than the natural vegetation *in that particular environment*. No species can grow in all environments, thus species which have a high interference potential under one set of conditions will not be equally as good under all sets of conditions. The adoption of an effective cover cropping program for Ontario Hydro will greatly depend on the development of a highly site oriented selection criteria for the cover crop selection.

## 4.2 Future Studies

### 4.2.1 The use of Ontario Hydro's existing cover cropped rights-of-way in the development of a cover crop program

Ontario Hydro has used cover crops in the past, and a study of these areas may represent one possible shortcut in evaluating the effectiveness of a cover crop approach. Unfortunately, previous investigations have indicated many drawbacks to this (Osmars 1975, Gillespie 1978, Suffling 1979). The inadequate documentation of the number of trees removed from the plots precludes the possibility of retroactively evaluating their effectiveness. However, it may be possible to use these areas as the starting point of field studies on established crops. This will be possible only if the plots were initially planted with an appropriate experimental design.

An appropriate design would be similar to the field study discussed in detailed below, namely a replicated planting of several crops and an appropriate control. A planting of only 1 or 2 species or mixtures at a given site is not sufficient to provide any useful ranking of the crops.

The existing cover crop program may also provide information needed to evaluate the longevity of the crops. This will not require an experimental design as rigorous as that discussed above, however, the results will only be useful if there is a sufficient variety of crops planted within a particular area.

Any investigation using Ontario Hydro's current cover crops is dependent upon finding the sites. This will require information of sufficient detail to relocate the plot boundaries to within 1 m of their original position.

### 4.2.2 New Experimentation

Studies from areas with vegetation comparable to Ontario's were not found by this literature search. Therefore no recommendations can be made as to which crops may form a competitive, stable cover on the rights-of-way. Research needs to be directed to achieve the following goals:

a) Determine plant species which have a high interference potential against the trees which are problematic in Ontario.

b) Determine the methods required to establish these species on the rights-of-way.

c) Determine the longevity of these crops on the right-of-way.

d) Determine which sections of the rights-of-way are best managed with a cover crop approach.

e) Determine criteria for the selection of appropriate species for operational usage on these sections.

Goals a), b) and e) can be achieved using experimentation at three possible scales (greenhouse, garden and field), while goals c) and d) can only be determined from a field study.

There is a limitless number of potential cover crop candidates (Suffling (1979) listed a total of 384 species which met his criteria). Many of these are native species which have no commercially available seed source. Therefore studies will require acquisition of propagules from the wild. A scanning procedure is required which will rapidly assess the interference potential of each species but require only a limited propagule supply. This is best achieved with a greenhouse study.

The interference potential is highly affected by the conditions under which the measurements are taken. Variations in site specific factors such as soil texture, nutrient levels, microtopography and disturbances (animal, human and climatic) will affect the outcome of a field study. In an initial screening, it is important to minimize as many of these variables as possible, while for the final selection, it is important to test the interference potential of each crop under several conditions.

A greenhouse study is defined as an experimental investigation of the interference effects of a several crops on the germination and/or growth of a selected tree species, conducted in a controlled environment in a small container. The advantages of this type of study are its high degree of experimental control and the small quantities of crop propagules required. A short experimental duration can be used, which allows for a faster turnover of experiments. Standardization of the soil texture, nutrient supply, watering regimes and the target tree species will allow for repeatable, preliminary screening of many crops. There is a danger in screening the crops under only one experimental regime that an excellent competitor for a different regime will be missed. Therefore it is recommended that each species be tested under several controlled moisture and nutrient combinations. The target for this study will be either a transplanted tree or a known amount of tree seeds placed in the pots.

A greenhouse experiment does have several drawbacks. The small scale is detrimental to the testing of shrub species. The experiment will be inherently short term, which may not allow a slower establishing crop to fully express its interference potential. Persistence of the crop cannot be determined. No disturbances of the crop will occur. (Disturbances often create openings in a canopy which allow for the invasion of trees). Animal effects cannot be estimated (grazing of the crop could effect its interference potential while girdling of trees by animals attracted by the crop may be a substantial proportion of its effectiveness (Popko 1973)).

One scale above a greenhouse study is the garden experiment. This involves the ploughing of an area of land and establishing numerous experimental plots. This type of experiment will still allow for the comparison of several crops, but with much less control and fewer numbers than a greenhouse study. Some limited experimental manipulation of soil moisture and nutrients are possible (additions only). The target for these experiments will still be tree seeds or transplants.

The primary advantage of this type of study is its duration. The plots can be maintained for several years. Estimates of the stability of the crop can actually be obtained, and this time frame

is more realistic for the maintenance cycles used on the rights-of-way. The number of crops tested is limited by the area available and the manpower required to establish and monitor the study. Plot sizes can be small (Wedin and Tilman (1989) used a 0.75 x 0.75 m plot for a 5-year study), but a high degree of replication will be required. The study will also be influenced by climatic variation. As a typical year seldom occurs, the study should be designed with several different starting years to overcome this problem.

The third level of study is a field experiment on operational or pseudo-operational rights-of-way. This represents the real world evaluation for the crops, but is only suitable for the final evaluation of a limited number of crops. This is the only experimental situation where the cover crop can be compared directly to the natural right-of-way vegetation, thus is the only stage of the procedure where the real value of the crop can be estimated. It suffers from all the disadvantages of the garden study, plus additional problems with human interference, replication and plot sizes. Natural invasion of the crops by trees can be monitored, although with the high variability in this process (the standard deviation of tree density is often higher than the mean (Osmars 1975)) it is highly recommended that evaluations using transplants or tree seeding are also undertaken. As with a garden experiment, variation in climate will necessitate the incorporation of multiple starting years in the experimental design, and the results will have a high degree of site specificity.

The following approach is recommended. A greenhouse study should be used to screen all species under a defined set of conditions, to select no more than 20 potential crops. These will then be tested in garden experiments of at least 5 year duration, with a minimum of 5 replicates per crop, and at least 2 starting times. Several gardens should be set up in areas of differing climate, moisture supply and soil conditions. From these experiments, a short list of species (5 to 6) will be recommended for testing on an operational right-of-way. These species will then be tested in the field, comparing their interference potential directly to the natural right-of-way vegetation. This comparison will again require an minimum of 5 replicates per crop, and should realistically be done on a province wide scale. To provide for a valid comparison between the cover crop approach and the current right-of-way management methods, the field experiments should be run for a minimum of 2 treatment cycles.

This may appear to be a rather drawn out and tedious procedure, but there are no realistic short cuts available. This time frame will be required for any study on rights-of-way management techniques. Any study which concerns tree growth must be long term. Such experiments are attempts to directly manipulate community dynamics, and a long equilibrium period is necessary to ensure that a real response is being measured instead of a transitory condition (Tilman 1989).

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

The literature review shows:

1. The rate and course of the succession from open fields to forests can be altered by the manipulation of either the vegetation or supply of resources.

2. Some investigations have shown that cover crops are more inhibitory to tree growth than the natural vegetation.

3. There are insufficient studies in regions with climate or vegetation comparable to Ontario's to recommend specific cover crops for use on the rights-of-way.

4. Greenhouse and garden experiments should be conducted to identify species with a high interference potential.

5. Field experiments should be conducted to evaluate the use of these species on the right-of-way.

Cover crops represent one of the many tools available for integrated vegetation management. It is unlikely that any one approach will be universally applicable to the rights-of-way. The effectiveness of each approach will change as advances are made in each area, and this will ultimately affect the relative costs for each approach. The policies and regulations which govern what is permissible have changed in the past (such as banning of the herbicide 2, 4, 5 T), at the present (the Corporate initiatives regarding environmental protection) and will change again in the future. To be a leader in the field of vegetation management and maintain our ability to improve on our system, it is important to continue research on all the maintenance techniques, including any new ones, and assess their potential application in today's environment.

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Appendix A: A list of plants referred to in this report.

| Common Name | Scientific Name |
|---|---|
| alder, red | *Alnus rubra* |
| alfalfa | *Medicago media* |
| ash | *Fraxinus excelsior* |
| ash, green | *Fraxinus pennsylvanica* |
| ash, white | *Fraxinus americana* |
| aspen, trembling | *Populus tremuloides* |
| Bahiagrass | *Paspalum notatum* |
| bamboo, dwarf | *Sasa pigmaea* |
| beech | *Fagus sylvatica* |
| bent grass,common | *Agrostis tenuis* |
| Bermuda grass | *Cynodon dactylon* |
| birch | *Betula* spp. |
| birch, paper | *Betula papyrifera* |
| birdsfoot trefoil | *Lotus corniculatus* |
| blackberry, trailing | *Rubus* sp. |
| blue gramma | *Bouteloua gracilis* |
| bluegrass, big | *Poa* sp. |
| bluegrass, kentucky | *Poa pratensis* |
| bluegrass, kentucky | *Poa pratensis* |
| brome grass | *Bromus inermis* |
| burnet, small | *Sanguisorba minor* |
| Calamagrostis rubescens | *Calamagrostis rubescens* |
| ceanothus | *Ceanothus velutinus* |
| cherry, black | *Prunus serotina* |
| chin. juniper | *Juniperus chinensis* |
| clover, crimson | *Trifolium incarnatum* |
| clover, red | *Trifolium pratense* |
| clover, subterranean | *Trifolium subteraneum* |
| clover, white | *Trifolium repens* |
| clover, yellow sweet | *Melilotus officinalis* |
| clover, yuchi | *Trifolium vesiculosum* |
| cottonwood | *Populus deltoides* |
| dogwood | *Cornus florida* |
| Douglas fir | *Pseudotsuga menziesii* |
| dwarf holly | *Ilex cornuta* |
| fescue, Arizona | *Festuca arizonica* |
| fescue, hard | *Festuca longifolia* |
| fescue, red | *Festuca rubra* |
| fescue, rough | *Festuca scabrella* |
| fescue, sheep | *Festuca ovina* |
| fescue, tall | *Festuca arundinacea* |
| fir, balsam | *Abies balsamea* |
| fir, Frasier | *Abies fraseri* |
| forsynthia | *Forsynthia intermedia* |
| golden vicary privet | *Ligustrum vicaryi* |
| greenleaf manzanita | *Arctostaphylos patula* |

| Common Name | Scientific Name |
|---|---|
| Hayscented fern | *Dennstaedtia punctilobula* |
| hemlock | *Tsuga canadensis* |
| Ivy, English | *Hedra helix* |
| Jap black pine | *Pinus thungergi* |
| Korean lespedeza | *Lespoedeza stipulaciea* |
| liriope | *Liriope muscari* |
| maple, Norway | *Acer plantanoides* |
| maple, red | *Acer rubrum* |
| maple, silver | *Acer saccharinum* |
| maple, sugar | *Acer saccharum* |
| maple, sycamore | *Acer pseudoplantanus* |
| meadow grass, rough | *Poa trivalis* |
| mountain muhly | *Muhlenbergia montana* |
| New York fern | *Thelypteris noveboracensis* |
| nimbleweed | *Muhlenbergia schreberii* |
| oak, nuttall | *Quercus nuttallii* |
| oatgrass, tall | *Arrhenatherum elatius* |
| orchard grass | *Dactylis glomerata* |
| peach | *Prunus persica* |
| pecan | *Carya illinoensis* |
| pine, loblolly | *Pinus taeda* |
| pine, ponderosa | *Pinus ponderosa* |
| pine, radiata | *Pinus radiata* |
| pine, red | *Pinus resinosa* |
| pine, scots | *Pinus sylvestris* |
| pine, slash | *Pinus echinata* |
| pine, sugar | *Pinus lambertiana* |
| pine, yellow | *Pinus* sp. |
| plantain | *Plantago lanceolata* |
| poplar, hybrid | *Populus deltoides* x *P. trichlocarpa* |
| quackgrass | *Agropyron repens* |
| ragweed | *Ambrosia artimesifolia* |
| raspberry | *Rubus idaeus* |
| red alder | *Alnus rubra* |
| red sorrel | *Rumex actosella* |
| red top | *Agrostis gigantea* |
| ryegrass, Italian | *Lolium multiflorum* |
| ryegrass, perennial | *Lolium perenne* |
| sequoia | *Sequoia washingtonia* |
| short husk grass | *Brachyelytrum erectum* |
| spruce, Norway | *Picea abies* |
| spruce, white | *Picea glauca* |
| squirrel tail | *Sitanion hystrix* |
| sumac | *Rhus copallina* |
| sweetgum | *Liquidambar styraciflua* |

| Common Name | Scientific Name |
|---|---|
| sycamore | *Plantanus occidentalis* |
| timothy | *Phleum pratense* |
| vetch, crown | *Coronella varia* |
| vetch, hairy | *Vicia villosa* |
| vetch, nova | *Vicia spp.* |
| walnut, black | *Jugulans nigra* |
| wheat | *Tricicum aestiyum* |
| wheatgrass, crested | *Agropyron desertorum* |
| wheatgrass, pubescent | *Agropyron sp.* |
| yarrow | *Achellia millefolia* |

Appendix B: A summary of the studies which investigated the interference potential (IP) of 1 or more cover crops on a tree species.

| Type of Cover Crop[1] | Tree Species | Tree age[2] | Length of Expt | Experimental Control[3] | Growth of Tree[4] Parameter | Control | Treatment | IP | Statistical Effects $p$[5] | rating | Ref.[6] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| alfalfa + | | 3 | 3 | natural | height | 71.1 | 55.9 | 79 | ? | | 1 |
| alfalfa + | | | 3 | natural | density | 12.0 | 2.0 | 17 | ? | | 1 |
| Bahiagrass | pine, slash | 1 | 1 | bare ground | dry wt | 6.8 | 2.6 | 38 | 0.05 | | 16 |
| bamboo, dwarf | cottonwood | | 1 | bare ground | dry wt | 35.0 | 26.0 | 74 | 0.05 | 3 out of 3 | 36 |
| bamboo, dwarf | maple, silver | | 1 | bare ground | dry wt | 77.0 | 72.0 | 94 | n | 3 out of 3 | 36 |
| bentgrass,common + | ash | sd | 3 | herbicide | height | 1.3 | 0.6 | 50 | 0.05 | | 8 |
| bentgrass,common + | maple, Norway | 3 | 2 | herbicide | height | 0.8 | 0.4 | 50 | 0.05 | | 8 |
| bentgrass,common + | ash | 3 | 3 | herbicide | height | 0.4 | 0.1 | 25 | 0.05 | | 8 |
| bentgrass,common + | ash | 3 | 3 | herbicide | dry wt | 1.1 | 0.6 | 55 | 0.05 | | 8 |
| bentgrass,common + | ash | sd | 3 | herbicide | dry wt | 2.8 | 1.4 | 50 | 0.05 | | 8 |
| bentgrass,common + | maple, Norway | 3 | 2 | herbicide | diameter | 0.8 | 0.5 | 60 | 0.05 | | 8 |
| bentgrass,common + | ash | sd | 3 | herbicide | diameter | 1.0 | 0.5 | 45 | 0.05 | | 8 |
| bentgrass,common + | ash | 3 | 3 | herbicide | diameter | 0.4 | 0.2 | 50 | 0.05 | | 8 |
| bentgrass, common + | apple | 30 | 6 | cultivated | diameter | 32.9 | 20.8 | 63 | ? | | 33 |
| Bermuda grass | chin. juniper | ? | 3 | herbicide | visual | 9.5 | 4.5 | 47 | 0.05 | | 51 |
| Bermuda grass | dwarf holly | ? | 3 | herbicide | visual | 6.5 | 1.3 | 20 | 0.05 | | 51 |
| Bermuda grass | vicary privet | ? | 2 | herbicide | visual | 8.1 | 2.2 | 27 | 0.05 | | 51 |
| Bermuda grass | Jap black pine | ? | 3 | herbicide | visual | 7.4 | 4.4 | 59 | 0.05 | | 51 |
| Bermuda grass | Jap black pine | ? | 3 | herbicide | height | 162.6 | 129.5 | 80 | 0.05 | | 51 |
| Bermuda grass | chin. juniper | ? | 3 | herbicide | height | 184.2 | 145.0 | 79 | 0.05 | | 51 |
| Bermuda grass | peach | 1 | 2 | cultivated | fresh wt | 4500.0 | 500.0 | 11 | y | | 49 |
| birdsfoot trefoil | poplar, hybrid | cutting | 4 | natural | height | 489.0 | 4.3 | 1 | 0.05 | | 25 |
| blackberry, trailing | apple | 2 | 4 | herbicide | diameter | 68.3 | 66.0 | 97 | 0.05 | 6 out of 6 | 39 |
| blue gramma | pine, ponderosa | 2 | 2 | weeded | survival | no effect | | 100 | n | | 14 |
| blue gramma | pine, ponderosa | 2 | 2 | weeded | height | 31.0 | 29.0 | 94 | n | 3 out of 3 | 14 |
| blue gramma | pine, ponderosa | 2 | 2 | weeded | diameter | 14.0 | 14.0 | 100 | n | 5 out of 5 | 14 |
| bluegrass, big | pine, ponderosa | 2 | 3 | natural | survival | 57.0 | 66.0 | 116 | ? | 2 out of 2 | 3 |
| bluegrass, Kentucky + | forsynthia | ? | 2 | cultivated | # shoots | 3.7 | 0.5 | 12 | 0.05 | | 15 |
| bluegrass, Kentucky + | apple | 4 | 2 | | fruit wt | 34000.0 | 24000.0 | 71 | 0.001 | 2 out of 2 | 41 |
| bluegrass, Kentucky + | apple | 4 | 2 | | fruit wt | 34000.0 | 3000.0 | 9 | 0.001 | 1 out of 2 | 41 |
| bluegrass, Kentucky + | dogwood | ? | 2 | cultivated | internode | 13.9 | 6.35 | 46 | 0.05 | | 15 |
| bluegrass, Kentucky + | forsynthia | ? | 2 | cultivated | height | 436.0 | 47.0 | 11 | 0.05 | | 15 |
| bluegrass, Kentucky + | ash | 3 | 3 | herbicide | height | 0.4 | 0.1 | 25 | 0.05 | | 8 |
| bluegrass, Kentucky + | ash | sd | 3 | herbicide | height | 1.3 | 0.6 | 50 | 0.05 | | 8 |
| bluegrass, Kentucky + | maple, Norway | 3 | 2 | herbicide | height | 0.8 | 0.4 | 50 | 0.05 | | 8 |
| bluegrass, Kentucky + | ash | sd | 3 | herbicide | dry wt | 2.8 | 1.4 | 50 | 0.05 | | 8 |
| bluegrass, Kentucky + | ash | 3 | 3 | herbicide | dry wt | 1.1 | 0.6 | 55 | 0.05 | | 8 |
| bluegrass, Kentucky + | dogwood | ? | 2 | cultivated | diameter | 5.5 | 3.2 | 58 | 0.05 | | 15 |
| bluegrass, Kentucky + | apple | 4 | 2 | | diameter | 13.9 | 12.9 | 93 | n | 2 out of 2 | 41 |
| bluegrass, Kentucky + | ash | sd | 3 | herbicide | diameter | 1.0 | 0.5 | 45 | 0.05 | | 8 |
| bluegrass, Kentucky + | apple | 4 | 2 | | diameter | 13.9 | 7.5 | 54 | 0.001 | 1 out of 2 | 41 |
| bluegrass, Kentucky + | ash | 3 | 3 | herbicide | diameter | 0.4 | 0.2 | 50 | 0.05 | | 8 |
| bluegrass, Kentucky + | maple, Norway | 3 | 2 | herbicide | diameter | 0.8 | 0.5 | 60 | 0.05 | | 8 |
| bluegrass, Kentucky | apple | sd | 1 | bare ground | dry wt | 35.0 | 28.0 | 80 | 0.001 | 3 out of 3 | 38 |

continued ...

Appendix B (continued)

| Type of Cover Crop[1] | Tree Species | Tree age[2] | Length of Expt | Experimental Control[3] | Growth of Tree[4] Parameter | Control | Treatment | IP | Statistical Effects $p$[5] | rating | Ref.[6] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| bluegrass, Kentucky | apple | 2 | 4 | herbicide | diameter | 68.3 | 50.0 | 73 | 0.05 | 3 out of 6 | 39 |
| brome grass | aspen, trembling | | 1 | bare ground | height | 111.0 | 73.0 | 66 | 0.01 | | 2 |
| brome grass | aspen, trembling | | 1 | bare ground | dry wt | 36.0 | 19.0 | 53 | 0.01 | | 2 |
| brome grass + | aspen,trembling | natural | 3 | natural | height | 71.1 | 55.9 | 79 | ? | | 1 |
| brome grass + | aspen,trembling | natural | 3 | natural | density | 12.0 | 2.0 | 17 | ? | | 1 |
| burnet, small | pine, ponderosa | 2 | 2 | weeded | survival | no effect | | 100 | n | | 14 |
| burnet, small | pine, ponderosa | 2 | 2 | weeded | height | 31.0 | 23.9 | 77 | 0.05 | 2 out of 3 | 14 |
| burnet, small | maple, sycamore | sd | 4 | weeded | height | 4.1 | 4.7 | 115 | n | | 9 |
| burnet, small | pine, ponderosa | 2 | 2 | weeded | diameter | 14.0 | 11.0 | 79 | 0.05 | 2 out of 5 | 14 |
| Calamagrostis rubescens | pine, ponderosa | 2 | 4 | herbicide | dry wt | 357.0 | 65.7 | 18 | 0.001 | | 28 |
| ceanothus | pine, yellow | 3 | 1 | no shrubs | survival | 53.0 | 89.0 | 168 | ? | | 44 |
| ceanothus + forbs | Douglas fir | 5 | 4 | herbicide | volume | 11616.0 | 2805.0 | 24 | ? | | 29 |
| ceanothus + forbs | Douglas fir | 5 | 4 | herbicide | height | 6279.0 | 219.0 | 3 | ? | | 29 |
| ceanothus + forbs | Douglas fir | 5 | 4 | herbicide | diameter | 60.0 | 34.0 | 57 | ? | | 29 |
| clover, crimson | sycamore | 2 | 4 | undefined | volume | 14.1 | 49.8 | 353 | 0.05 | 2 out of 4 | 18 |
| clover, crimson | sycamore | 2 | 4 | undefined | height | 160.0 | 540.0 | 338 | 0.05 | 2 out of 4 | 18 |
| clover, red + | Douglas fir | 1 | 3 | natural | survival | no effect | | 100 | n | | 13 |
| clover, red + | Douglas fir | 1 | 3 | natural | height | 47.4 | 50.1 | 106 | n | | 13 |
| clover, red + | apple | 30 | 6 | cultivated | diameter | 32.9 | 24.7 | 75 | ? | | 33 |
| clover, red + | Douglas fir | 1 | 3 | natural | diameter | 12.2 | 12.0 | 99 | n | | 13 |
| clover, subterranean | sycamore | 2 | 4 | undefined | volume | 14.1 | 57.0 | 404 | 0.05 | 1 out of 4 | 18 |
| clover, subterranean | sycamore | 2 | 4 | undefined | height | 160.0 | 580.0 | 363 | 0.05 | 1 out of 4 | 18 |
| clover, white | maple, sycamore | sd | 4 | weeded | height | 4.1 | 5.2 | 127 | n | | 9 |
| clover, white | birch | sd | 2 | weeded | height | 626.0 | 0.0 | 0 | 0.05 | | 9 |
| clover, white | fir, Fraser | 3 | 1 | bare ground | height | no effect | | 100 | n | | 47 |
| clover, white | fir, Fraser | 3 | 1 | bare ground | dry wt | 10.7 | 6.6 | 61 | 0.05 | | 47 |
| clover, white | apple | 4 | 5 | natural | diameter | 53.0 | 50.0 | 94 | n | 3 out of 3 | 5 |
| clover, white | fir, Fraser | 3 | 1 | bare ground | diameter | no effect | | 100 | n | | 47 |
| clover, white | birch | sd | 2 | weeded | density | 113.0 | 0.0 | 0 | 0.05 | | 9 |
| clover, white + | apple | 4 | 2 | | fruit wt | 34000.0 | 24000.0 | 71 | 0.001 | 2 out of 2 | 41 |
| clover, white + | apple | 30 | 6 | cultivated | diameter | 32.9 | 20.8 | 63 | ? | | 33 |
| clover, white + | apple | 30 | 6 | cultivated | diameter | 32.9 | 24.7 | 75 | ? | | 33 |
| clover, white + | apple | 30 | 6 | cultivated | diameter | 32.9 | 18.4 | 56 | ? | | 33 |
| clover, white + | apple | 4 | 2 | | diameter | 13.9 | 12.9 | 93 | n | 2 out of 2 | 41 |
| clover, yellow sweet | pine, ponderosa | 2 | 2 | weeded | survival | no effect | | 100 | n | | 14 |
| clover, yellow sweet | pine, ponderosa | 2 | 2 | weeded | height | 31.0 | 23.4 | 75 | 0.05 | 2 out of 3 | 14 |
| clover, yellow sweet | pine, ponderosa | 2 | 2 | weeded | diameter | 14.0 | 12.0 | 86 | 0.05 | 3 out of 5 | 14 |
| fescue, Arizona | pine, ponderosa | 2 | 2 | bare ground | dry wt | 10.7 | 2.1 | 19 | ? | | 23 |
| fescue, hard | pine, ponderosa | 2 | 3 | natural | survival | 57.0 | 66.0 | 116 | ? | 2 out of 2 | 3 |
| fescue, red | birch | sd | 2 | weeded | height | 626.0 | 0.0 | 0 | 0.05 | | 9 |
| fescue, red | maple, sycamore | sd | 4 | weeded | height | 4.1 | 5.0 | 122 | n | | 9 |
| fescue, red | birch | sd | 2 | weeded | density | 113.0 | 0.0 | 0 | 0.05 | | 9 |
| fescue, red + | forsynthia | ? | 2 | cultivated | # shoots | 3.7 | 0.5 | 12 | 0.05 | | 15 |
| fescue, red + | apple | 4 | 2 | | fruit wt | 34000.0 | 3000.0 | 9 | 0.001 | 1out of 2 | 41 |
| fescue, red + | dogwood | ? | 2 | cultivated | internode | 13.9 | 6.35 | 46 | 0.05 | | 15 |

continued ...

Appendix B (continued)

| Type of Cover Crop[1] | Tree Species | Tree age[2] | Length of Expt | Experimental Control[3] | Growth of Tree[4] Parameter | Control | Treatment | IP | Statistical Effects $p$[5] | rating | Ref.[6] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| fescue, red + | aspen,trembling | natural | 3 | natural | height | 71.1 | 55.9 | 79 | ? | | 1 |
| fescue, red + | forsynthia | ? | 2 | cultivated | height | 436.0 | 47.0 | 11 | 0.05 | | 15 |
| fescue, red + | dogwood | ? | 2 | cultivated | diameter | 5.5 | 3.2 | 58 | 0.05 | | 15 |
| fescue, red + | aspen,trembling | natural | 3 | natural | density | 12.0 | 2.0 | 17 | ? | | 1 |
| fescue, rough + | aspen, trembling | 0 | 3 | natural | height | 71.1 | 55.9 | 79 | ? | | 1 |
| fescue, rough + | aspen,trembling | 0 | 3 | natural | density | 12.0 | 2.0 | 17 | ? | | 1 |
| fescue, sheep + | apple | 30 | 6 | cultivated | diameter | 32.9 | 20.8 | 63 | ? | | 33 |
| fescue, tall | sweetgum | sd | 1 | bare ground | survival | 100.0 | 0.0 | 0 | 0.01 | | 45 |
| fescue, tall | sweetgum | sd | 1 | bare ground | survival | 100.0 | 100.0 | 100 | 0.05 | | 45 |
| fescue, tall | sweetgum | sd | 1 | bare ground | survival | 100.0 | 50.0 | 50 | 0.05 | | 45 |
| fescue, tall | walnut, black | ? | ? | natural | survival | 79.1 | 78.5 | 99 | n | | 43 |
| fescue, tall | sweetgum | sd | 1 | bare ground | height | 100.0 | 100.0 | 100 | 0.01 | | 45 |
| fescue, tall | sweetgum | sd | 1 | bare ground | height | 100.0 | 40.0 | 40 | 0.01 | | 45 |
| fescue, tall | walnut, black | ? | ? | natural | height | 319.4 | 182.6 | 57 | 0.001 | | 43 |
| fescue, tall | sweetgum | sd | 1 | bare ground | dry wt | 100.0 | 70.0 | 70 | 0.01 | | 45 |
| fescue, tall | sweetgum | sd | 1 | bare ground | dry wt | 100.0 | 10.0 | 10 | 0.01 | | 45 |
| fescue, tall | walnut, black | ? | ? | natural | diameter | 39.9 | 13.5 | 34 | 0.001 | | 43 |
| fescue, tall | apple | 2 | 4 | herbicide | diameter | 68.3 | 31.0 | 45 | 0.05 | 1 out of 6 | 39 |
| greenleaf manzanita | pine, ponderosa | 1 | 2 | weeded | RRG canopy | 15.0 | 5.6 | 37 | 0.01 | | 34 |
| Hayscented fern | cherry, black | 1 | 3 | herbicide | survival | 71.0 | 19.0 | 27 | 0.05 | | 20 |
| Hayscented fern | cherry, black | 1 | 3 | herbicide | height | 74.0 | 73.0 | 99 | n | | 20 |
| Ivy, English | maple, silver | | 1 | bare ground | dry wt | 77.0 | 27.0 | 35 | 0.05 | 1 out of 3 | 36 |
| Ivy, English | cottonwood | | 1 | bare ground | dry wt | 35.0 | 23.0 | 66 | 0.05 | 1 out of 3 | 36 |
| Korean lespedeza | apple | sd | 1 | bare ground | dry wt | 35.0 | 25.0 | 71 | 0.001 | 2 out of 3 | 38 |
| Korean lespedeza | apple | 2 | 4 | herbicide | diameter | 68.3 | 59.0 | 86 | 0.05 | 4 out of 6 | 39 |
| liriope | maple, silver | | 1 | bare ground | dry wt | 77.0 | 40.0 | 52 | 0.05 | 2 out of 3 | 36 |
| liriope | cottonwood | | 1 | bare ground | dry wt | 35.0 | 28.0 | 80 | 0.05 | 2 out of 3 | 36 |
| meadow grass, rough + | apple | 30 | 6 | cultivated | diameter | 32.9 | 18.4 | 56 | ? | | 33 |
| meadow grass, rough + | apple | 30 | 6 | cultivated | diameter | 32.9 | 20.8 | 63 | ? | | 33 |
| meadow grass, rough + | apple | 30 | 6 | cultivated | diameter | 32.9 | 24.7 | 75 | ? | | 33 |
| mountain muhly | pine, ponderosa | 2 | 2 | bare ground | dry wt | 10.7 | 4.6 | 42 | ? | | 23 |
| New York fern | cherry, black | 1 | 3 | herbicide | survival | 74.0 | 19.0 | 26 | 0.05 | | 20 |
| New York fern | cherry, black | 1 | 3 | herbicide | height | 74.0 | 73.0 | 99 | n | | 20 |
| nimbleweed | apple | 2 | 4 | herbicide | diameter | 68.3 | 62.0 | 91 | 0.05 | 4 out of 6 | 39 |
| oatgrass, tall | pine, ponderosa | 2 | 3 | natural | survival | 57.0 | 44.0 | 77 | ? | 1 out of 2 | 3 |
| orchard grass | pine, ponderosa | 2 | 2 | weeded | survival | no effect | | 100 | n | | 14 |
| orchard grass | pine, ponderosa | 2 | 3 | natural | survival | 57.0 | 44.0 | 77 | ? | 1 out of 2 | 3 |
| orchard grass | pine, ponderosa | 2 | 2 | weeded | height | 31.0 | 23.5 | 76 | 0.05 | 2 out of 3 | 14 |
| orchard grass | fir, Fraser | 3 | 1 | bare ground | height | no effect | | 100 | n | | 47 |
| orchard grass | apple | sd | 1 | bare ground | dry wt | 35.0 | 25.0 | 71 | 0.001 | 2 out of 3 | 38 |
| orchard grass | fir, Fraser | 3 | 1 | bare ground | dry wt | 10.7 | 5.9 | 55 | 0.05 | | 47 |
| orchard grass | apple | 2 | 4 | herbicide | diameter | 68.3 | 40.0 | 59 | 0.05 | 2 out of 6 | 39 |
| orchard grass | fir, Fraser | 3 | 1 | bare ground | diameter | no effect | | 100 | n | | 47 |
| orchard grass | pine, ponderosa | 2 | 2 | weeded | diameter | 14.0 | 11.0 | 79 | 0.05 | 1 out of 5 | 14 |
| orchard grass + | Douglas fir | 1 | 3 | natural | survival | no effect | | 100 | n | | 13 |

continued ...

Appendix B (continued)

| Type of Cover Crop[1] | Tree Species | Tree age[2] | Length of Expt | Experimental Control[3] | Growth of Tree[4] Parameter | Control | Treatment | IP | Statistical Effects $p$[5] | rating | Ref.[6] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| orchard grass + | Douglas fir | 1 | 3 | natural | height | 47.4 | 50.1 | 106 | n | | 13 |
| orchard grass + | apple | 30 | 6 | cultivated | diameter | 32.9 | 18.4 | 56 | ? | | 33 |
| orchard grass + | Douglas fir | 1 | 3 | natural | diameter | 12.2 | 12.0 | 99 | n | | 13 |
| plantain | maple, sycamore | sd | 4 | weeded | height | 4.1 | 7.0 | 171 | 0.05 | | 9 |
| quackgrass | poplar, hybrid | cutting | 4 | natural | height | 489.0 | 5.5 | 1 | 0.05 | | 25 |
| ragweed | apple | 2 | 4 | herbicide | diameter | 68.3 | 43.0 | 63 | 0.05 | 2 out of 6 | 39 |
| raspberry | spruce, white | ? | 9 | Mountain maple | height | 22.6 | 7.0 | 31 | ? | | 4 |
| raspberry | fir, balsam | ? | 9 | mountain maple | height | 18.0 | 4.3 | 24 | ? | | 4 |
| red alder | Douglas fir | 2 | 5 | herbicide | height | 0.8 | 0.5 | 67 | y | | 11 |
| red alder | Douglas fir | 2 | 5 | herbicide | dry wt | 2000.0 | 1522.0 | 76 | y | | 11 |
| red sorrel | apple | sd | 1 | bare ground | dry wt | 35.0 | 23.0 | 66 | 0.001 | 1 out of 3 | 38 |
| red sorrel | apple | 2 | 4 | herbicide | diameter | 68.3 | 60.0 | 88 | 0.05 | 5 out of 6 | 39 |
| red top | pine, ponderosa | 2 | 3 | natural | survival | 57.0 | 66.0 | 116 | ? | 2 out of 2 | 3 |
| ryegrass, Italian | maple, sycamore | sd | 4 | weeded | height | 4.1 | 4.9 | 120 | n | | 9 |
| ryegrass, perennial | pine, ponderosa | 2 | 3 | natural | survival | 57.0 | 44.0 | 77 | ? | 1 out of 2 | 3 |
| ryegrass, perennial | birch | sd | 2 | weeded | height | 626.0 | 0.0 | 0 | 0.05 | | 9 |
| ryegrass, perennial | apple | 30 | 6 | cultivated | diameter | 32.9 | 24.7 | 75 | ? | | 33 |
| ryegrass, perennial | apple | 4 | 5 | natural | diameter | 53.0 | 20.0 | 38 | 0.05 | 1 out of 3 | 5 |
| ryegrass, perennial | birch | sd | 2 | weeded | density | 113.0 | 0.0 | 0 | 0.05 | | 9 |
| ryegrass, perennial + | apple | 30 | 6 | cultivated | diameter | 32.9 | 20.8 | 63 | ? | | 33 |
| ryegrass, perennial + | apple | 30 | 6 | cultivated | diameter | 32.9 | 18.4 | 56 | ? | | 33 |
| short husk grass | cherry, black | 1 | 3 | herbicide | survival | 98.0 | 73.0 | 74 | n | | 20 |
| short husk grass | cherry, black | 1 | 3 | herbicide | height | 135.0 | 125.0 | 93 | n | | 20 |
| squirrel tail | pine, ponderosa | 2 | 2 | weeded | survival | no effect | | 100 | n | | 14 |
| squirrel tail | pine, ponderosa | 2 | 2 | weeded | height | 31.0 | 28.4 | 92 | n | 3 out of 3 | 14 |
| squirrel tail | pine, ponderosa | 2 | 2 | weeded | diameter | 14.0 | 14.0 | 100 | n | 5 out of 5 | 14 |
| sumac | tree | natural | | grass | density | 0.023 | 0.95 | 4130 | 0.01 | | 30 |
| timothy | pine, ponderosa | 2 | 3 | natural | survival | 57.0 | 44.0 | 77 | ? | 1 out of 2 | 3 |
| timothy | apple | 4 | 5 | natural | diameter | 53.0 | 23.0 | 43 | 0.1 | 2 out of 3 | 5 |
| timothy + | Douglas fir | 1 | 3 | natural | survival | no effect | | 100 | n | | 13 |
| timothy + | ash | sd | 3 | herbicide | height | 1.3 | 0.6 | 50 | 0.05 | | 8 |
| timothy + | Douglas fir | 1 | 3 | natural | height | 47.4 | 50.1 | 106 | n | | 13 |
| timothy + | ash | 3 | 3 | herbicide | height | 0.4 | 0.1 | 25 | 0.05 | | 8 |
| timothy + | maple, Norway | 3 | 2 | herbicide | height | 0.8 | 0.4 | 50 | 0.05 | | 8 |
| timothy + | ash | sd | 3 | herbicide | dry wt | 2.8 | 1.4 | 50 | 0.05 | | 8 |
| timothy + | ash | 3 | 3 | herbicide | dry wt | 1.1 | 0.6 | 55 | 0.05 | | 8 |
| timothy + | apple | 30 | 6 | cultivated | diameter | 32.9 | 24.7 | 75 | ? | | 33 |
| timothy + | ash | 3 | 3 | herbicide | diameter | 0.4 | 0.2 | 50 | 0.05 | | 8 |
| timothy + | maple, Norway | 3 | 2 | herbicide | diameter | 0.8 | 0.5 | 60 | 0.05 | | 8 |
| timothy + | ash | sd | 3 | herbicide | diameter | 1.0 | 0.5 | 45 | 0.05 | | 8 |
| timothy + | Douglas fir | 1 | 3 | natural | diameter | 12.2 | 12.0 | 99 | n | | 13 |
| vetch, hairy | sycamore | 2 | 4 | undefined | volume | 14.1 | 35.4 | 251 | n | 3 out of 4 | 18 |
| vetch, hairy | sycamore | 2 | 4 | undefined | height | 160.0 | 520.0 | 325 | 0.05 | 3 out of 4 | 18 |
| vetch, nova | sycamore | 2 | 4 | undefined | volume | 14.1 | 20.8 | 148 | n | 4 out of 4 | 18 |
| vetch, nova | sycamore | 2 | 4 | undefined | height | 160.0 | 360.0 | 225 | n | 4 out of 4 | 18 |

continued ...

Appendix B (continued)

| Type of Cover Crop[1] | Tree Species | Tree age[2] | Length of Expt | Experimental Control[3] | Growth of Tree[4] Parameter | Control | Treatment | IP | Statistical Effects $p$[5] | rating | Ref.[6] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| wheat | apple | 2 | 4 | herbicide | diameter | 68.3 | 63.0 | 92 | 0.05 | 5 out of 6 | 39 |
| wheatgrass, crested | pine, ponderosa | 2 | 2 | weeded | survival | no effect | | 100 | n | | 14 |
| wheatgrass, crested | pine, ponderosa | 2 | 2 | weeded | height | 31.0 | 21.8 | 70 | 0.05 | 1 out of 3 | 14 |
| wheatgrass, crested | pine, ponderosa | 2 | 2 | weeded | diameter | 14.0 | 10.0 | 71 | 0.05 | 1 out of 5 | 14 |
| wheatgrass, crested + | aspen,trembling | natural | 3 | natural | height | 71.1 | 55.9 | 79 | ? | | 1 |
| wheatgrass, crested + | aspen,trembling | natural | 3 | natural | density | 12.0 | 2.0 | 17 | ? | | 1 |
| wheatgrass, pubescent | pine, ponderosa | 2 | 3 | natural | survival | 57.0 | 66.0 | 116 | ? | 2 out of 2 | 3 |
| yarrow | maple, sycamore | sd | 4 | weeded | height | 4.1 | 4.2 | 102 | n | | 9 |
| yuchi clover | sycamore | 2 | 4 | undefined | volume | 14.1 | 48.2 | 342 | 0.05 | 2 out of 4 | 18 |
| yuchi clover | sycamore | 2 | 4 | undefined | height | 160.0 | 520.0 | 325 | 0.05 | 2 out of 4 | 18 |

1 + indicates that a species was part of a mixture

2 sd indicates target tree was a naturally occuring seedling.
natural indicates target tree was a naturally occuring tree of unspecifiec age.

3 herbicide, weeded and cultivated indicate the method used to establish and maintain the bare ground experimental control. Natural indicates that the native vegetation was used as the reference instead of bare ground.

4 Growth is an annual increment (final-initial / years)
Units are diameter mm $y^{-1}$ height cm $y^{-1}$
density stems $m^{-2}$ survival % planted
dry weight g $yr^{-1}$ volume $cm^3$ $yr^{-1}$

5 y indicates there was a statistical difference but the study did not provide a $p$ level
n indicates there was no statistical difference but the study did not provide a $p$ level
? indicates that insufficient information was presented to estimate a statistical difference

6 See Table 3 for source codes.

Appendix C: A summary of the studies which investigated the interference potential (IP) of an natural vegetation on a tree species.

| Type of Cover Crop[1] | Tree Species | Tree age[2] | Length of Expt | Experimental Control[3] | Growth of Tree[4] Parameter | Control | Treatment | IP | Statistical Effects $p$[5] | rating | Ref.[6] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| grass | beech | 3 | 1 | herbicide | height | 5.0 | 0.0 | 0 | n | | 12 |
| RoW vegetation | alder, red | | 5 | natural | density | 1.9 | 0.0 | 0 | | | 50 |
| forbs | Douglas fir | 5 | 4 | herbicide | height | 6279.0 | 259.0 | 4 | ? | | 29 |
| natural | pine, loblolly | 1 | 2 | herbicide | diameter | 52.0 | 10.0 | 19 | | | 53 |
| natural | sycamore | 1 | 4 | cultivated | diameter | 104.7 | 32.0 | 31 | y | | 21 |
| natural | pine, loblolly | 1 | 2 | herbicide | height | 170.0 | 60.0 | 35 | | | 53 |
| natural | pecan | 1 | 4 | cultivated | diameter | 20.3 | 7.3 | 36 | y | | 21 |
| natural | sweetgum | 1 | 4 | cultivated | diameter | 53.8 | 20.3 | 38 | y | | 21 |
| natural | ash, green | 1 | 4 | cultivated | diameter | 93.0 | 37.8 | 41 | y | | 21 |
| natural | cottonwood | 1 | 4 | cultivated | diameter | 110.5 | 45.1 | 41 | y | | 21 |
| natural | oak, nuttall | 1 | 4 | cultivated | diameter | 42.2 | 17.4 | 41 | y | | 21 |
| grass | fir, fraser | 4 | 3 | herbicide | diameter | 28.7 | 12.1 | 42 | 0.05 | 1 out of 2 | 46 |
| natural | oak, nuttall | 1 | 4 | cultivated | height | 191.9 | 87.2 | 45 | y | | 21 |
| natural | cottonwood | 1 | 4 | cultivated | height | 645.3 | 314.0 | 49 | y | | 21 |
| grass | Douglas fir | 2 | 5 | herbicide | dry wt | 2000.0 | 1000.0 | 50 | y | | 11 |
| grass | fir, fraser | 4 | 3 | herbicide | survival | 93.0 | 47.0 | 51 | | | 7 |
| forbs | spruce, Norway | 4 | 3 | herbicide | diameter | 25.0 | 12.8 | 51 | 0.05 | same | 46 |
| forbs | fir, fraser | 4 | 3 | herbicide | diameter | 28.7 | 15.3 | 53 | 0.05 | 2 out of 2 | 46 |
| natural | sycamore | 1 | 4 | cultivated | height | 479.7 | 261.6 | 55 | y | | 21 |
| natural | pecan | 1 | 4 | cultivated | height | 78.5 | 43.6 | 56 | y | | 21 |
| natural | ash, green | 1 | 4 | cultivated | height | 409.9 | 234.5 | 57 | y | | 21 |
| grass | spruce, Norway | 4 | 3 | herbicide | diameter | 25.0 | 14.9 | 60 | 0.05 | same | 46 |
| natural | sweetgum | 1 | 4 | herbicide | height | 226.7 | 139.5 | 62 | y | | 21 |
| grass | fir, fraser | 4 | 3 | herbicide | height | 26.0 | 16.0 | 62 | ? | | 7 |
| forbs | Douglas fir | 5 | 4 | herbicide | volume | 11616.0 | 7241.0 | 62 | ? | | 29 |
| forb | fir, fraser | 4 | 3 | herbicide | survival | 93.0 | 60.0 | 65 | | | 7 |
| grass | pine, scots | 2 | 3 | herbicide | height | 46.0 | 31.0 | 67 | ? | | 7 |
| grass | pine, scots | 2 | 3 | herbicide | survival | 87.0 | 60.0 | 69 | | | 7 |
| forb | fir, fraser | 4 | 3 | herbicide | height | 26.0 | 18.0 | 69 | ? | | 7 |
| forb | pine, scots | 2 | 3 | herbicide | height | 46.0 | 35.0 | 76 | ? | | 7 |
| forb | pine, scots | 2 | 3 | herbicide | survival | 87.0 | 67.0 | 77 | | | 7 |
| grass | Douglas fir | 2 | 5 | herbicide | height | 0.8 | 0.6 | 77 | y | | 11 |
| grass + shrub | pine | ? | 5 | herbicide | volume | 0.1 | 0.1 | 82 | ? | | 17 |
| forb | spruce, Norway | 4 | 3 | herbicide | height | 71.5 | 59.6 | 83 | 0.05 | same | 46 |
| grass | spruce, Norway | 4 | 3 | herbicide | height | 71.5 | 59.6 | 83 | 0.05 | same | 46 |
| natural | tree | 1 | 4 | cultivated | survival | 91.0 | 76.0 | 84 | y | | 21 |
| natural | pine, red | 7 | 2 | cultivated | diameter | 9.1 | 7.6 | 84 | | | 22 |
| forb | Douglas fir | 5 | 4 | herbicide | diameter | 60.0 | 51.0 | 85 | ? | | 29 |
| grass | fir, fraser | 4 | 3 | herbicide | height | 66.4 | 57.9 | 87 | n | | 46 |

continued ...

Appendix C (continued)

| Type of Cover Crop[1] | Tree Species | Tree age[2] | Length of Expt | Experimental Control[3] | Growth of Tree[4] Parameter | Control | Treatment | IP | Statistical Effects $p$[5] | rating | Ref.[6] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| grass | pine | ? | 5 | herbicide | volume | 0.1 | 0.1 | 89 | ? | | 17 |
| natural vegetation | pine, ponderosa | 2 | 2 | weeded | height | 31.0 | 28.4 | 92 | n | 3 out of 3 | 14 |
| natural vegetation | pine, ponderosa | 2 | 2 | weeded | diameter | 14.0 | 13.0 | 93 | 0.05 | 4 out of 5 | 14 |
| forb | fir, fraser | 4 | 3 | herbicide | height | 66.4 | 63.0 | 95 | n | | 46 |
| natural | pine, red | 7 | 2 | herbicide | height | 54.5 | 53.4 | 98 | | | 22 |
| natural vegetation | pine, ponderosa | 2 | 2 | weeded | survival | no effect | | 100 | n | | 14 |
| grass | beech | 3 | 1 | herbicide | survival | no effect | | 100 | n | | 12 |
| shrub | pine | ? | 5 | herbicide | volume | 0.1 | 0.1 | 113 | ? | | 17 |
| grass | beech | 3 | 1 | herbicide | diameter | 3.7 | 10.7 | 289 | 0.05 | | 12 |
| natural | Pine, radiata | | 8 | herbicide | diameter | 7.9 | 22.4 | 284 | | | 53 |
| natural | Pine, radiata | | 8 | herbicide | height | 38 | 106 | 279 | | | 53 |

1 + indicates that a species was part of a mixture

2 sd indicates target tree was a naturally occuring seedling.
natural indicates target tree was a naturally occuring tree of unspecifiec age.

3 herbicide, weeded and cultivated indicate the method used to establish and maintain the bare ground experimental control. Natural indicates that the native vegetation was used as the reference instead of bare ground.

4 Growth is an annual increment (final-initial / years)
Units are diameter mm $y^{-1}$ height cm $y^{-1}$
density stems $m^{-2}$ survival % planted
dry weight g $yr^{-1}$ volume $cm^3$ $yr^{-1}$

5 y indicates there was a statistical difference but the study did not provide a $p$ level
n indicates there was no statistical difference but the study did not provide a $p$ level
? indicates that insufficient information was presented to estimate a statistical difference

6 See Table 3 for source codes.

Appendix D: A summary of the studies involving field observation on vegetation cover and tree growth.

| Type of Vegetation[1] | Tree Species | Tree age[2] | Length of Expt | Experimental Control[3] | Growth of Tree[4] Parameter | Control | Treatment | IP | Statistical Effects $p$[5] | rating | Ref.[6] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| blackberry | ? | | | | easily invaded | | | | | | 6 |
| blueberry, low | ? | | | | resists invasion | | | | | | 6 |
| blueberry, low late | ? | natural | | patch margin | density | 18.9 | 2.4 | 13 | | | 27 |
| blueberry, low late | ? | | | | easily invaded | | | | | | 6 |
| blueberry, low + | ? | | | | easily invaded | | | | | | 31 |
| blueberry + | ? | | | | resists invasion | | | | | | 6 |
| blueberry + | ? | | | | easily invaded | | | | | | 6 |
| bluegrass, Canada | birch, paper | | | unseeded RoW | resists invasion | | | | | | 42 |
| brome grass | ash, white | | | unseeded RoW | resists invasion | | | | | | 42 |
| brome grass | maple, sugar | | | unseeded RoW | resists invasion | | | | | | 42 |
| brome grass + | maple, sugar | | | unseeded RoW | resists invasion | | | | | | 42 |
| brome grass + | ash, white | | | unseeded RoW | resists invasion | | | | | | 42 |
| shrub | pine, sugar | 2 | 2 | no shrubs | survival | 32.7 | 86.2 | 264 | | | 37 |
| shrub | pine, ponderosa | 3 | 1 | no shrubs | survival | 62.6 | 77.8 | 124 | | | 37 |
| shrub | sequoia | 3 | 1 | no shrubs | survival | 0.0 | 68.0 | | | | 37 |
| ceanothus | pine, ponderosa | 3 | 1 | no shrubs | survival | 55.0 | 78.0 | 142 | | | 37 |
| ceanothus | Douglas fir | natural | | no shrubs | survival | 36.5 | 52.9 | 145 | | | 52 |
| clubmoss | cherry, black | natural | | bare ground | height | 253.0 | 298.0 | 118 | n | 3 out of 3 | 19 |
| clubmoss | maple, red | natural | | bare ground | density | 22.4 | 23.6 | 105 | n | 3 out of 3 | 19 |
| clubmoss | cherry, black | natural | | bare ground | density | 210.1 | 109.7 | 52 | n | 3 out of 3 | 19 |
| clubmoss | maple, sugar | natural | | bare ground | density | 4.2 | 1.5 | 36 | 0.01 | 1 out of 3 | 19 |
| clubmoss | maple, red | natural | | | density | 0.4 | 0.3 | 63 | 0.005 | | 24 |
| clubmoss | cherry, black | natural | | | density | 0.3 | 0.2 | 60 | 0.1 | | 24 |
| clubmoss | hemlock | natural | | | density | 1.0 | 0.2 | 22 | 0.001 | | 24 |
| fescue, meadow | ? | | | | resists invasion | | | | | | 6 |
| goldenrod,grass leaved + | ? | | | | resists invasion | | | | | | 6 |
| goldenrod, rough | ? | | | | resists invasion | | | | | | 6 |
| greenbrier | ? | natural | | patch margin | density | 2.8 | 0.0 | 0 | | | 27 |
| greenleaf manzanita | pine, ponderosa | 3 | 1 | no shrubs | survival | 49.0 | 70.0 | 143 | | | 37 |
| greenleaf manzanita | Douglas fir | | | no shrubs | | | | | 0.05 | | 32 |
| greenleaf manzanita | pine, ponderosa | | | no shrubs | | | | | 0.05 | | 32 |
| hayscented fern | birch | natural | | | density | 0.2 | 0.1 | 50 | 0.001 | | 24 |
| hayscented fern | cherry, black | natural | | | density | 0.5 | 0.1 | 25 | 0.000 | | 24 |
| hayscented fern | hemlock | natural | | | density | 2.5 | 0.5 | 18 | 0.000 | | 24 |
| hayscented fern | maple, red | natural | | | density | 0.7 | 0.1 | 17 | 0.000 | | 24 |
| hayscented fern | maple, sugar | natural | | bare ground | density | 2.7 | 1.0 | 36 | n | 2 out of 3 | 19 |
| hayscented fern | cherry, black | natural | | bare ground | height | 458.0 | 155.0 | 34 | 0.01 | 1 out of 3 | 19 |
| hayscented fern | maple, red | natural | | bare ground | density | 37.5 | 7.0 | 19 | 0.05 | 2 out of 3 | 19 |
| hayscented fern | cherry, black | natural | | bare ground | density | 198.9 | 32.9 | 17 | 0.01 | 1 out of 3 | 19 |
| hayscented fern | ? | | | | easily invaded | | | | | | 6 |
| hayscented fern + | ? | | | | easily invaded | | | | | | 31 |
| huckleberry | ? | natural | | patch margin | density | 5.1 | 0.1 | 3 | | | 27 |
| huckleberry | ? | | | | easily invaded | | | | | | 6 |
| huckleberry + | ? | | | | easily invaded | | | | | | 31 |

continued ...

Appendix D (continued)

| Type of Vegetation[1] | Tree Species | Tree age[2] | Length of Expt | Experimental Control[3] | Growth of Tree[4] Parameter | Control | Treatment | IP | Statistical Effects $p$[5] | rating | Ref.[6] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| little bluestem | ? | natural | | patch margin | density | not reported | | | 0.0 | | 27 |
| loosestrife | ? | | | | | easily invaded | | | | | 6 |
| nannyberry | | | | | | resists invasion | | | | | 26 |
| New York fern | maple, sugar | natural | | bare ground | density | 1.3 | 2.5 | 186 | n | 2 out of 3 | 19 |
| New York fern | cherry, black | natural | | bare ground | height | 357.0 | 164.0 | 46 | 0.01 | 1 out of 3 | 19 |
| New York fern | cherry, black | natural | | bare ground | density | 240.7 | 50.6 | 21 | 0.01 | 1 out of 3 | 19 |
| New York fern | maple, red | natural | | bare ground | density | 38.2 | 4.8 | 12 | 0.01 | 1 out of 3 | 19 |
| New York Fern + | ? | | | | | easily invaded | | | | | 31 |
| oak, bear | ? | | | | | resists invasion | | | | | 6 |
| oak, bear + | ? | | | | | resists invasion | | | | | 6 |
| oak, bear + | ? | | | | | easily invaded | | | | | 6 |
| partridge berry | hemlock | natural | | | density | 0.9 | 5.0 | 550 | 0.000 | | 24 |
| partridge berry | maple, red | natural | | | density | 0.5 | 0.9 | 200 | 0.05 | | 24 |
| sainfoil + | maple, sugar | | | unseeded RoW | | resists invasion | | | | | 42 |
| sheep laurel + | ? | | | | | easily invaded | | | | | 31 |
| short husk grass | maple, sugar | natural | | bare ground | density | 2.3 | 5.7 | 250 | n | 2 out of 3 | 19 |
| short husk grass | cherry, black | natural | | bare ground | height | 466.0 | 272.0 | 58 | n | 2 out of 3 | 19 |
| short husk grass | cherry, black | natural | | bare ground | density | 177.2 | 90.7 | 51 | 0.05 | 2 out of 3 | 19 |
| short husk grass | maple, red | natural | | bare ground | density | 38.8 | 18.3 | 47 | n | 3 out of 3 | 19 |
| shrub | Douglas fir | 3 | 1 | no shrubs | survival | 38.5 | 66.5 | 173 | | | 10 |
| sweetfern + | ? | | | | | easily invaded | | | | | 31 |
| sweetfern | ? | | | | | easily invaded | | | | | 6 |
| timothy + | ash, white | | | unseeded RoW | | resists invasion | | | | | 42 |
| timothy + | birch, paper | | | unseeded RoW | | easily invaded | | | | | 42 |
| timothy + | maple, sugar | | | unseeded RoW | | resists invasion | | | | | 42 |
| vetch, crown | ? | natural | | no vetch | density | 0.1 | 0.0 | 12 | | | 35 |
| wood sorrel | hemlock | natural | | | density | 0.0 | 0.0 | 113 | 0.1 | | 24 |

1 + indicates that a species was part of a mixture

2 sd indicates target tree was a naturally occuring seedling.
natural indicates target tree was a naturally occuring tree of unspecifiec age.

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4 Growth is an annual increment (final-initial / years)
Units are diameter mm $y^{-1}$ height cm $y^{-1}$ dry weight g $yr^{-1}$
density stems $m^{-2}$ survival % planted volume $cm^3$ $yr^{-1}$
resists invasion and easily invaded are subjective comments supplied by researchers

5 y indicates there was a statistical difference but the study did not provide a $p$ level
n indicates there was no statistical difference but the study did not provide a $p$ level
? indicates that insufficient information was presented to estimate a statistical difference

6 See Table 3 for source codes.